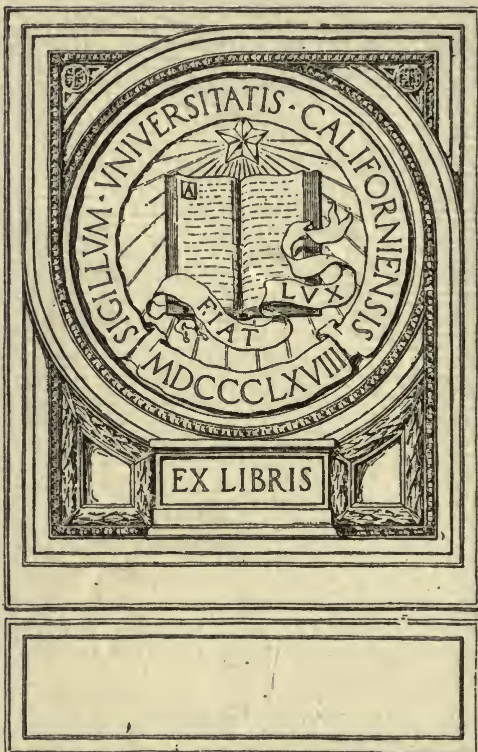
FARM DEVELOPMENT

WILLET M. HAYS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Farm Development

An Introductory Book in Agriculture

Including a Discussion of Soils, Selecting & Planning Farms, Subduing the Fields, Drainage, Irrigation, Roads, Fences, Together with Introductory Chapters Concerning Farm Business, and the Relations of General Science to Agriculture

By

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PREFACE

This book was prepared from notes used in giving instruction to classes in the Agricultural High School—of secondary grade—of the University of Minnesota. The students were nearly all from farm homes and nearly all expected to return to the country to live. Their needs, and the point of view in compiling this book, are those of the common farmer. In editing these notes an effort has been made to adapt the text to the agricultural high school, to the consolidated rural and village school, and even to advanced classes in the rural district school, and to the needs of the farmer's home library. Since no attempt is here made more than to introduce the several subjects, the farmer or pupil reading this book who wishes to pursue the subject in detail should seek advice of the State agricultural college and the Department of Agriculture as to the best up-to-date available literature published by public and private agencies.

The chapters dealing with rural engineering are designed to give to the farmer a general explanation of drainage, road making, etc., for his own use rather than to train him for service in engineering. The engineer's point of view is only incidental, and the rural engineer's interest will be mainly confined to the practical suggestions. Very helpful aid in revising the manuscript has been rendered by my associates, Messrs. Andrew Boss, C. P. Bull, John Thompson, William G. Smith, John G. Haney, E. C. Parker, H. H. Mowry and Maurice O. Eldridge.

W. M. HAYS.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FARM DEVELOPMENT

CHAPTER I

INTRODUCTION

Agricultural science and art deal with the production, from the soil, of foods, clothing, wood and other useful materials. Many of the natural sciences have a theoretical and a practical bearing on this greatest of the productive industries; and the arts which have a useful relation to farming are numerous and varied. In no other vocation are the sciences and the arts so extensively and intimately interwoven.

While some persons with comparatively little book learning make money by farming, there is no other vocation in which there is so much useful and interesting knowledge that applies directly to the business and to the home. Differing from any other vocation, the business and the home are here a unit; and the family-sized farm, the "family farm," is our most important business, educational, social, and racial institution. In no other element of our national organization is Americanism so well exemplified; its democracy is well-nigh complete. None other of our institutions is more worthy of being copied by the people of other countries, because the separate family farm, supplemented by the consolidated "farm school," uniting the apprenticeship work of the farm and the home with the general and technical work of the farm school, will provide the best conditions under which to develop superior races of men and women. The farmer and the farm home maker need to exercise great wisdom in selecting, from the mass of daily experience and from book knowledge, practical facts and theories which are of the highest importance in acquiring success under his or her environment.

Home training.—Most of the plain farm arts, as plowing, sowing, harvesting, feeding, breeding, buying and selling, and much of the mechanical work of the farm, are best learned by everyday practice in the business. This is also the case with the home arts, as cooking, sewing, house decorating, home making, entertaining and character building. Without practical experience the would-be farmer is not adept in selecting the practical methods and theories from the great mass of available thought and adapting them to his conditions. Those who have more theoretical knowledge than practical experience are not inclined to be conservative in adopting new theories and new practices; on the other hand, those who lack training in scientific theory are not usually capable of working out new things of practical importance. A combination of theoretical and practical knowledge is necessary for the best success in any line of effort; and in no line of business is this more true than in farming.

Technical and scientific as well as practical knowledge is of daily and yearly value in the home and on the farm; and in these progressive times every person should be constantly in the attitude of an inquirer, a student. All the agencies yielding useful information should be utilized. Agricultural periodicals, books on agricultural subjects, speeches at farmers' institutes and other farmers' meetings are sources of much information regarding farm life and farm business. Much of the best information and many theories of farm and farm home management may be acquired by young farmers from their parents and from intelligent folk with whom they associate. Consultation with those who have made a success of any special line of home or farm development is probably the most important source of information and advice. Personal friends, to whom one can trust his plans for suggestive and curative advice, are most important agencies to be employed with conservative freedom by farmers whose isolation makes necessary an effort to measure their plans through the minds of others. Giving suggestions to a friend is one of the opportunities for doing good; and every true man and woman sacredly keeps confidences given while another is asking advice.

Technical education in agriculture.—Schools to promote the professions have long been organized. More recently, schools for the business vocations and for the mechanical trades are being established; schools of agriculture, which earlier proved difficult of development, have in recent years been made to succeed, and schools of household economics have been even later in their development. Schools designed to give instruction in agriculture and farm home making have as wonderful possibilities in building up rural business and country life as have schools of medicine in advancing the cause of preventive and curative medicine. Schools which teach agriculture are most useful to those persons who are so fortunate as to receive the advantages they afford before settling down to life's business of home making and farming. These schools have also a very great value in giving dignity, profit, and comfort to farmers as a class, and in providing more and cheaper farm products for all classes of people. These schools teach the underlying principles which govern farm and home management and add to the practical knowledge which every farm boy or girl acquires in youth. Many of the erroneous notions gained from the experiences of one isolated farm, or from practical people who sometimes have wrong theories, are here corrected. By coming in daily contact with able teachers and bright fellow-students, the boy or girl from the farm is enabled to obtain a broader view of the questions of life and business. At the same time, the use of the naturalist's microscope, the chemist's crucible and balance, and other instruments of precision, trains the student's eye so that he sees and appreciates many things on the farm which previously had little or no meaning. The daily routine of class work, of note and essay writing, of searching for references, of recitation in class, and of work in the literary societies, places the mind of the pupil on a new plane. He returns home with new power to do the thinking necessary to higher development in farm life.

The young man gains dexterity in the arts of carpentry, blacksmithing, dairying, breeding, feeding, and in the raising and handling of forage, grain, garden and other crops; the young woman becomes more expert in the arts of cookery, sewing and home keeping; while both gain added power in character building in the home and in the community. Broader views of farm planning, farm improvement, and farm management are also acquired. The mind is made more active and more accurate; formal processes of figuring and planning and of doing things are learned; the books from which to seek specific information are made known; and at the same time the hand is trained to execute work with greater precision. Even systematic military and physical training are provided by the state in its local and general schools which instruct in agriculture, thus giving the students complete body development. By doing things with hand and mind under a trained expert, a student learns to do them accurately and to think clearly and rapidly. Dealing both with things and with printed pages, the mind does not lose its originality and versatility, as when the education deals only with the words of books.

Education consists largely in the training of the judgment. Practical experience in life gives more natural training than does attending school. But the intense training of the school—the training to think consecutively and logically, and to do things well under supervision—the establishment of ideals, and the storing of a broad knowledge, make the school a necessary part of a person's experience. The education of practical experience and of the school must be combined to produce the well-rounded man or woman. The more practical education of the industrial and technical school subjects trains the judgment to deal with things. The modern stock judging or corn judging class, for example, gives the mind a grasp on the practical differences in values which make wealth, and gives the man a confidence in himself and an ability to do things as well as to think things. "Instruction in judging is closely akin to training the common sense, and is the highest class of pedagogy."

The Nation and the States have come to recognize that the business of farming is peculiarly aided by vocational education in agriculture and home economics. Since the people of the farm are somewhat isolated, it is especially important that young people who are to be the future farmers should go to schools where they can make farming and farm home making a study under a faculty of strong technical teachers, and where they can have acquaintance and experience among large numbers of people.

It is wise economy on the part of the State to establish schools where a large percentage of the young farmers can get a good education in agriculture and home making along with schooling in the general subjects. By increasing the ability of the individual to make his work produce more, the State gains a larger income, and the individual and national life become richer and more highly developed. The young men or the young women who spend a few years in the technical study of those practical things with which they must deal every day of their lives, get much benefit from the means expended by the State for agricultural schools, and in turn they may be, and are, more useful to their neighboring citizens and to the State.

The fact that, for every dollar the student spends for his education, the State and the Nation pay another, puts him in debt to the country; and he should show profound gratitude by being a more successful, a more useful and a more public-spirited citizen. Agriculture demands the best exercise of both the brain and muscle of the youth, and thus aids in building up strong character. Agriculture should be fostered; it should be aided to the utmost so that our lands, growing in productiveness, and the inherited and acquired character of our country people may continue to be the enduring foundations of the republic.

Our statesmen and educators should co-operate in devising a system of country life education which will enable those who work the land to own it in farms of family size. Though it might appear that the large estate with transient or semi-peasant labor would produce food and clothing for the Nation more cheaply than does the family farm, folks are the land's supreme product; and when the land is divided off into family farms, needing only occasional outside help, the production per square mile of farm homes and of high-type Americans is greatly increased.

The larger values per acre of farm lands, the larger income per acre and per farm worker, the better investment in farm buildings, fences, machinery and live stock, all being made possible and increased by modern discovery, invention and organization, and the larger production of better farm folks, make possible any reasonable expenditure for education in country life subjects. The system of schools outlined above will increase taxes on land and on personal property. It will, however, take off such a load of ignorance, of wasted opportunity, of poor crops, of unprofitable animals, of loss in marketing, of political inefficiency, of undeveloped social enjoyments, and of unlovely country homes, that its annual cost will more than be made up every quarter of a year. America can no more afford to do without an efficient system of education, adapted to those who are to manage its farms and its farm homes, which will bring to the farmers the full benefit of modern knowledge, facilities and organization, than it could afford to discard modern railways.

Institutions devoted to education for country life.— In 1862, during the Civil war, the Congress of the United States took two important steps to organize technical education in agriculture. The first provided for institutions to build up a body of scientific knowledge of agriculture; to serve both as a general fund of information to all who farm and as the substance of instruction in agriculture in schools. The second provided for a system of schools especially devoted to country life. Along with the latter, provisions were also made for education in mechanic arts, the combined work being provided for in a State college of agriculture and the mechanic arts in each State; and education in home economics has grown up in these institutions along with education in the productive industries.

The scientific institutions which have grown out of the first of these acts of Congress are the United States Department of Agriculture and about fifty State agricultural experiment stations. The State stations were not organized till later, but they are a part of the same movement, and part of their support is annually appropriated by Congress. These institutions employ thousands of men engaged in research in all phases of agriculture. Many of the states have appropriated money for branch stations, and the United States Department of Agriculture also has established outposts for research under its control. In this way the State and the Nation are able to study farm management and many special questions relating to farming, on each large area of definite kind of soil and in each climatic and agricultural area. All the leading countries of the world are conducting agricultural researches, though no other has so extensive an organization as the United States. In the nineteenth century, there was spent in this way, in the world, probably $25,000,000, and appropriations for this purpose are being so rapidly increased that there will have been spent more than twice that amount in the first decade of the twentieth century. By the time farm youths born in 1900 are in middle life, there will have accumulated a body of agricultural knowledge resulting from an investment of probably $500,000,000. These expenditures are resulting in a large accumulation of scientific and practical facts useful to farmers and farm home makers. From this great mass of knowledge, teachers are gradually sorting out portions which are peculiarly adapted to use in making text-books for schools for farm youth. It would seem good statesmanship to assume that this knowledge will successfully knock at the doors even of our rural schools and there find a place beside the three R's, so that each farm boy and girl may have the key to this vast store of knowledge, and that our schools will be developed to bring this information successfully to all youths who are to become farmers.

While Congress provided only for colleges of agriculture, the movement which was crystallized into the Federal law of 1862 has resulted also in developing agricultural education in schools below collegiate grade. Thus a number of agricultural high schools of secondary school grade have been successfully organized; agriculture has also found its way with some degree of success into the secondary courses of public schools in cities, towns, villages and consolidated rural schools, and even in the elementary courses of the district rural schools. The three distinctive kinds of schools in which agricultural education will be most intensively and successfully taught are State agricultural colleges; large agricultural high schools, probably one for each ten counties; and consolidated rural and village schools to which the pupils are taken in school wagons. The State normal schools also are preparing to do especially good service in fitting teachers to instruct in agriculture, and many of the colleges of agriculture are establishing educational departments in which to make a specialty of helping prepare the large number of teachers needed. Many city and town public schools, also non-public schools of all grades, including universities, will also provide more or less instruction relating to the farm and farm home, and the aggregate of their work will be considerable.

But the bulk of the work will be done in an articulated system made up of the four classes of schools which are attended mainly by pupils from the farm, most of whom are to manage farms and farm homes. These are, first, district rural schools, usually with one room, to which the pupils walk; and while these schools are destined to give way in well-settled farm communities to the larger school next named, probably a hundred thousand will remain in sparsely settled and isolated communities. Schools of the second class are formed by consolidating six or eight one-room schools in the open country, and the pupils are transported to and from the schools, for the most part, in school wagons. These consolidated rural schools (of which we should have 20,000 or 30,000, located on small school farms among farms, and giving instruction to pupils from farm homes) to distinguish them from district rural schools, may properly be called farm schools, as Grant Farm School, Owl Creek Farm School. Schools of the third class are on large school farms, provide dormitories, or allow the pupils to board in the adjoining town, are of secondary grade, and are called agricultural high schools. They receive students from consolidated rural schools and from the district rural schools, also from village and town schools, most of whom return to the farm, but they also prepare students to enter the agricultural college. The State agricultural colleges constitute the fourth class. In a few States they are separate institutions; in others they are joined with colleges of mechanic arts and colleges of science; and in yet other cases the agricultural college is one of a group of colleges making up the State university.

In the district rural school some subjects relating to agriculture and home making may be successfully taught by well-prepared teachers. Some rather inexpensive equipment can be afforded, and the practical facilities of the farm and the farm home may be used extensively. Here the preparation of the teacher is the paramount consideration.

The consolidated rural school, or farm school, receives pupils from a district four to six miles across. It has a ten-acre farm, a four or five-room school building, a cottage for the principal and small farm buildings. On the half of the school farm which is used for a combined campus and farmstead, there are groves, orchards, gardens, ornamental trees, shrubs and flowers and ample playgrounds. On the other half, are field crops on miniature fields and plats. The pupils, under the instruction of the teacher who is trained to teach agriculture, use all these plantings as a working laboratory. The older pupils attend school only six months and the alternating six months they help raise crops on the home farm. The principal can help the parents supervise their work and make the summer a truly educational period of apprenticeship in the actual business of farming. In like manner the assistant principal, who is trained to teach home economics, can visit the older girls in their homes during the vacation and thus supplement the instruction given in cooking, sewing and other household subjects taught during the winter in school. Thus the one to two hundred farms and farm homes in the consolidated rural school district are great laboratory adjuncts to the farm school.

The large agricultural high school has a group of trained technical teachers in agriculture and home economics, each with such equipment as is necessary to demonstrate and give practice in the various special lines taught.

The agricultural college is still more highly equipped with technical teachers, laboratories, libraries and facilities to give training preparatory to teaching research or other public or private service in agriculture or home economics, as well as for the practical affairs of the farm and the farm home.

The college receives students from agricultural high schools or from other secondary schools giving an equivalent of preparation. The agricultural high school receives pupils from the district rural school; and from the consolidated rural, village or town school where a partial agricultural high school course is given, students are received with such advanced standing as their advancement warrants. The consolidated rural school provides the elementary eight-year course, and often one, two or more years of the high school course. A system under which many farm pupils can secure the elementary course and two years of high school work in the consolidated rural school, or in the village or town school, and a two-year finishing course in a large agricultural high school, would suit the needs of hundreds of thousands who are to be farmers and farm home-makers. The expense in time and money would not be too great and the education and inspiration for good farming, superior home-making and enlightened citizenship thus sustained in the open country will be beyond our fondest dreams. Boys from villages, cities and sparsely settled districts who wish to learn farming, can often secure places on good farms where they can work in summer and attend the consolidated rural school or the agricultural high school in winter.

This general scheme of four classes of schools, closely interwoven as a part of our entire school system, promises to provide both general and vocational school facilities for nearly all who are to live on farms. At the same time, vocational as well as general training is being developed for those who work in the non-agricultural industries. Thus vocational education in the productive industries and in home making promises to follow technical education for the professions. When all the schools needed to provide vocational training for the vast numbers of those who are to work on the farm, in the shop and in the home are thus developed, the specialization of those designed to teach these specific subjects will be produced by normal schools and normal departments in secondary and collegiate schools, as now teachers are prepared to teach the general school subjects. The preparation of teachers will be the great problem only during the period of rapidly developing vocational education, and during that period wages for those who can successfully introduce these subjects will be relatively high and the service most useful and attractive.

CHAPTER II

FARMING AS A VOCATION

Farming a good business.—Since all lines of human endeavor are open to free competition, people flock into any vocation which temporarily seems especially profitable, and they as quickly leave a vocation which becomes unprofitable, all industries thus being kept at nearly the average in opportunity. The law of supply and demand, in the main, controls. Farming is, on the whole, a conservative line of business, though often subject to severe variations in the profit it affords. In farming, few men become millionaires, and few paupers. It is not a line of the greatest financial opportunities nor of the greatest misfortunes. Its money rewards average less than those of the average city vocations, but including with things money will buy, those things money will not purchase, or for which cash is not needed, farming furnishes as much, or more, on the average, of remuneration as does effort applied in the average of other vocations. In conducting the family-sized farm, the minor portion of the remuneration comes in the form of money, while good food, clothing, a beautiful home, wholesome outdoor employment, independence, and other useful and enjoyable features of rural life constitute the larger portion.

State benefited by a strong race of farmers.—The changed conditions of modern times require a smaller proportion of the whole people on the farms than formerly; only about one-third of all engaged in gainful operations in the United States are now tillers of the soil, and the indications are that this will be further reduced to one-fourth of the whole, when the ratio must become nearly static. Labor-saving machinery makes it possible for fewer people to produce the food and raw material of clothing required for all classes of people than formerly; while, on the other hand, the cities require more workers in manufacturing industries, in commerce, in transportation, in the professions and in special and personal service. Standards of living have changed and the average person demands much more of the non-agricultural commodities than formerly, while the amount of foods and fibers required by each person remains nearly stationary. The satisfaction of these increased demands gives profitable employment to more people in the cities. On the other hand, the average farmer can produce more than formerly, because of better methods and machinery, which make his labor more efficient. There is a constant migration of the farmers to the cities, especially to the large cities of America and other civilized countries, and nearly all cities the world over are growing rapidly. This movement from land to town is influenced mainly by economic conditions, but our educational system has led people to overestimate the professions and to undervalue the opportunities of such vocations as farming, mechanics, and home making, where more physical labor is required.

On the other hand, the growth of farm population does not keep pace with the city population, and in some localities, as in New England and Scotland, the actual number of farmers is much smaller than formerly. With the advent of periods of better times, there is a strong movement of farmers to the cities. This movement is temporarily checked by panics, or periods when business is depressed, but, as the decades pass, the population of the cities grows faster than that of the country, because relatively larger numbers find employment in the cities. This movement will continue as long as the needs for workers in the town industries and professions grow more rapidly than do the needs for workers in the rural industries. Some people prefer the associations of the towns and cities, others prefer the quiet, independent and healthful life on the farm. There are larger opportunities in the cities for a few persons who happen to be especially gifted in business or as specialists in given lines of work, but the opportunities of the country average as well, or better, than the opportunities of the city and the chances of utter failure are far greater in the city than in the country.

The home is the most influential institution in our national life, and the farm home is the best place to produce strong and useful citizens. The farm home is racially our most important home. Farmers are rather conservative and are peculiarly loyal to the good of the community. Their voice usually rings true for sound and good government, though they are sometimes slow to embrace improvements in governmental affairs. The Nation needs to retain men and women on our rich lands who are so trained as citizens, as well as farmers, as to be capable of maintaining our country life at a high standard. It is interested in the farmer's prosperity, because the general well-being of the rural community insures for the future a strong race of people, and prosperity among the producing classes insures prosperity to all classes and to the Nation. Too large a proportion of the whole people on farms is not desirable, as competition in the production of farm commodities should not be so strong that the farm family cannot secure the profits necessary to supply not only good food and clothing, but to provide for education, books, opportunities for travel, etc. The farmer's sons and daughters need to be well fed and well clothed, and not only taught industry and morality, but given excellent business and educational advantages in general, and taught how gradually to enrich the soil. Improved farm machinery and home appliances, and better methods, have aided in vastly improving the conditions of work and living on the farm, but further improvements are needed to keep country life apace with the rapidly improving life of the city.

Studying agriculture is interesting and useful.—A course of study in efficient agricultural schools and colleges gives much pleasure, because the studies include interesting things in nature, in business, in the home life, and in the affairs of man generally; and after leaving school for practical life, the student finds a continuous source of very great pleasure in his acquaintance with the practical means and processes of nature, and in his knowledge of how better to work with man. Nature's classics are not in a man-made book, but are spread out in passive and active forms about the farm. Each animal, plant, and field is a word, a sentence, or a page. Each day is a chapter, and each year is a grand book full of substantial structures, sturdy industry, exacting duties, wonderful opportunities, noble impulses, interesting life, gracious friendships, warm-hearted loves, and the rhythmic music of the revolving forces and spirits of inanimate and animate nature. The man or woman who remains in country life, not following the tide to the city, receives a wonderful inspiration from special study in an agricultural school.

Methods of work and trade relations are changing. Perfected means of transportation throw each farmer into competition with all the world, and the world has learned how to produce all things more cheaply. Intelligence, coupled with business capacity, is even more of an advantage in farming now than when prices were better and our competitors were not so earnestly studying all the questions relating to their business. The American farmer gets on because he is enterprising. If his neighbor invents a machine he makes use of it. If some enterprising firm manufactures this machine for our competitors in the Argentine Republic, India, or some other country where, with their cheaper land or cheaper labor, they can undersell us, we must find a still better machine or process and make profits by using it before these competitors have learned how. We must keep pace in intelligence with the foremost nations of the world.

Many of our lands are losing their virgin productivity, some of our fields are becoming infested with weeds, and we must all follow the example of our best farmers and set about building up our soils to a standard better than their original fertility. We must learn newer and better methods of field management and superior ways of handling crops. We must find new crops, new uses of old crops, and we must improve our staple crops. We must improve our live stock and our methods of rearing them. We must make the best possible use of dairy and other animal products, and we must learn to condense freights and market our produce to the best advantage; and most important of all, we must learn to live well, and to make for ourselves and our families the best that our opportunities will afford.

Farming is rising in the scale among vocations.— Farming is becoming established on a firmer basis; many important facts are being discovered concerning plants, animals and soils, and a great many mechanical devices of value to the farmer are being constantly developed. Plans of farm management are being so perfected that farming is gradually being brought out of the realm of mere drudgery. Farm organization is being reduced to a scientific basis similar to engineering. As our eyes are being trained to see the interesting things of the farm, so our minds are being educated to appreciate the basal facts of animal and plant growth. And as our knowledge of the philosophy of farm management and of plant and animal production becomes more concrete and practical, we become awakened to the interesting and uplifting features of country life. As we learn how to organize and manage the farm home, how to develop the youthful members of the family into useful men and women, as we become masters in carrying out the everyday practical work of the farm and the farm home, we realize the advantages of life in the country. The conditions of the country are so changing that competition is drawing closer about farm production, and exact work must be done to earn comfortable rewards. On the other hand, the rural delivery of mails, rural telephones, better roads, bicycles, carriages, rural electric railways, books and papers of superior quality and at reduced prices, are coming within the reach of all. Labor-saving devices on the farm and in the house, improved breeds of plants and animals, cheaper clothing, lessened cost of transportation, and other advantages, which have come with modern times, also make farm life still more desirable and the farm home a better place for the development of character in the boys and girls who are fortunate in passing their earlier years with sturdy and truthful nature rather than amid the often adverse conditions obtaining in the crowded city. Farmers who are really equipped to take advantage of all modern facilities will reap a larger reward financially than at any former time.

CHAPTER III

AGRICULTURAL SUBSTANCES CARRY FORCE

At the beginning of a technical study of agriculture the student needs to see clearly that the substances of soil and air, the force constantly sent to the earth by the sun, the organizing forces of heredity in living plants and animals, the willing and the directing powers of man and the needs of the human race are the five great elemental things concerned in the making of farm products. The nations are rapidly awakening to the fact that scientific research, plant and animal breeding, school education, extension teaching and actual demonstration are destined very greatly to increase the farm production per acre and per farm worker. They are beginning to invest vast sums of money in agricultural advancement as a great corporation invests in improvements in its business. The farmers are arousing themselves to the full value of new knowledge, superior plant and animal forms, and to systematic training for the callings of farming and farm home making.

Plant compounds are storage batteries.—Plant materials consist of compounds of the elements gathered from the soil and air and stowed away during their growth. It may be said that no real growth has been made by a plant until the green appears in the stem or leaf. Before this, the enlargement of the plantlet has been accomplished by using up the food materials stored in the seed. This leaf green, or chlorophyll, as it is called, is made of small oblong bodies called chloroplasts, colored green with a coloring matter termed chlorophyll. These chlorophyll bodies do not appear in plants that are kept in the dark. Seeds and roots that begin growth in the dark will grow only while the food material lasts which is stored in the parent seeds or roots.

The work done by these chlorophyll bodies in the leaves, aided by the sunlight, is very important. The leaves of plants are very complex workshops, or laboratories, and here the substances taken from the soil and air by the plant are brought together, and by the action of the sunlight on these in connection with the chlorophyll bodies, the plant chemical compounds are manufactured. This process is not fully understood, but we may liken these compounds of which the plant is composed to "storage batteries." They contain a definite amount of force which can be liberated and used. When plants are burned, the heat produced comes from these "storage batteries," or compounds. Upon burning, the substances coming from the air return to the air in the form of a gas called carbonic acid gas (CO_2); another small portion of the plant called mineral, which the plant secured from the soil, is left as ashes. Water in the plant is also changed, upon burning, to the gas we call watery vapor.

The force or energy we see operating in the world has its origin in the sun. Plants are able to absorb from the sun's rays some of this force and store it in latent form in the compounds of which they are made up. Animals eat plants, and their digestive organs in breaking up some of the storage batteries, are capable of setting free some of this force, and we see the result in the work they do, and in the warmth of their bodies. They transform some of the plant compound into animal compound, and these, retaining the sun force stored up in the plant compounds, become animal storage batteries. Animals are not capable of making the compounds that they need from the elements in the air and soil, nor of storing up force from the sun. They must depend entirely on plants, or in case of carnivorous animals, on animals which have eaten plants. So we have the true saying, "All flesh is grass."

But the reverse, all grass is flesh, is not true, for the animal is not able to use all the compounds of the plant. The part used by the animal depends on several things. In some plants the compounds are much more easily broken up than in others, and the animal secures a greater amount of available energy than from those plants where a considerable portion of energy is not digested or where the process of digestion consumes much of the energy. Certain animals have better digestive systems, and are capable of breaking up more of these compounds than others. When food is plentiful the animal may eat more than is necessary; and if food is scarce, it may digest the plants more completely. In either case the animal uses the compounds as fuel in the body to keep up body heat, to produce energy for locomotion and other vital functions, or to furnish to its young as milk. The parts of the plants eaten that cannot be used, are excreted as waste.

Latent energy in plants and animals.—Energy first stored up from the sun by the plant is said to be in a latent form. This may be illustrated by placing a partially melted piece of ice in a kettle on a stove, and beside it a kettle full of water, both being at the freezing temperature when placed over the fire. Heat is conducted into the water in both kettles, but the water in the kettle with the ice remains at the same temperature until the ice is melted, while the water in the other kettle rises in temperature. Heat is constantly going into each mass of water. In one it is stored up in the latent form, that is, used in merely changing the form of the water from a solid to a liquid without causing a rise in temperature. In the other it is stored up in the active form, resulting in a rapid rise in temperature. If the two kettles are now placed in air at the freezing temperature, the active heat from the hot water will again be given off, the heat radiating into the colder surrounding air, while none will be given off from the other kettle which has remained at the freezing temperature.

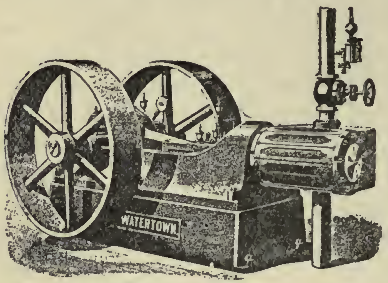


Figure. 1. Engine with single steam chest.

The coal or wood used in the engine has heat, or energy, in a latent form, and by setting it on fire this heat, so to speak, is extracted from the fuel, while the compounds of which the fuel is made are destroyed or broken down into simpler chemical compounds. The part of the wood which the tree got from the soil as mineral plant food is left on the grate when we use the wood as fuel, and we call it ashes. That part of the fuel which the plant got from the air becomes gas again, and goes up the chimney as a part of the smoke. The heat gathered from the sun's rays is liberated from the fuel and is radiated, or thrown off. It may be conducted into water in the boiler of the engine and cause the water to expand into steam. When the heat from the fuel in the fire-box under the boiler has been transferred to the water in the boiler and has changed it into steam, we have this force in a very active form expanding the steam. By conducting this active steam to the cylinder of

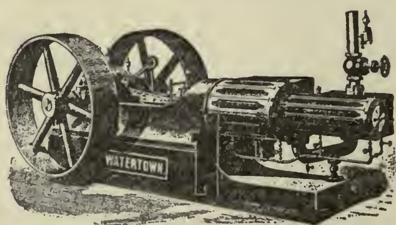


Figure 2. The tandem compound engine, Figure 2, has a second steam chest, which uses the exhaust, or partially used steam, from the first chest, thus securing 10 or 15 per cent more energy out of the steam than the engine with a single steam chest.

an engine and allowing it to expend its force on the piston, the force, or energy, which was liberated from the fuel by the fire, is transferred to the movement of the engine. In doing this the steam is partially condensed, or changed again to water—the heat has been liberated. The movement or power produced by the steam in the engine may be conducted by means of a belt to a mill or other machinery, or to an electric dynamo, where the force is changed again into another form of energy. This electricity here generated may be conducted for miles over wires, turned into an electric motor and used as power for various purposes, or it may be made again to give up its energy in the form of heat. This heat may be used to produce steam in another boiler, or to warm houses, or it may be changed to the form of light in an electric lamp and used to illuminate our dwellings and streets.

Figure 3. Common wheat. The average yield of 89 samples of common Blue Stem wheat grown in various parts of Minnesota in 1902 was 18.3 bushels per acre.

The plant, then, is a storage battery in which is stored up, from the sun, energy which may be appropriated for use by animals. Animals having incorporated into their bodies many of these plant storage batteries, usually somewhat changed in composition, they also become reservoirs of energy. If man eats the flesh of an animal and utilizes its force in the form of labor, he is simply drawing upon the supply of energy that the plants stored up from the vast resources of the sun.

Figure 4. A new wheat originated by selection. The average yield of 89 samples of Minnesota No. 169, a newly-bred wheat, originated from the parent Blue Stem shown in Figure 1, grown in various parts of Minnesota in 1902 under similar conditions as the common wheat, shown in Figure 3, was 21.5 bushels per acre, an increase of 3.3 bushels, or 18 per cent.

Specialized plants and animals.—Just as the machinist tries to improve the boiler and engine that shall best receive and transmit from the fuel the force it liberates upon burning, so the farmer seeks the best plants with which to gather and store up the force of the sun's rays and transmit them to his uses whenever wanted. As the electrician seeks the most economical form of dynamo to receive the force transmitted from the steam engine, so the farmer seeks the best horse, milch cow, or other animal that shall in the most economical manner receive the force from the plants and transmit it to whatever use may be desired. Some chemical compounds, within the plant or animal, form storage batteries of much greater powers than others. Thus, fats have nearly two and one-half times as much latent heat, or power, stored up in a given weight as have starches and sugars, or the substance of cell walls of plants, called cellulose. Various compounds called proteins are also rated high in value, because in addition to supplying energy they nourish the muscles, nerves, bones, etc. Plants which are bred so as to have a large percentage of protein and fat compounds have a special value, because they contain much more available latent energy than do those not so bred. In like manner, animals that are so well bred that their carcasses of beef, mutton or pork have a larger percentage of the high-priced lean meat are especially valuable because of the larger amounts of these more useful forms of "storage batteries." The dairy cow which transforms

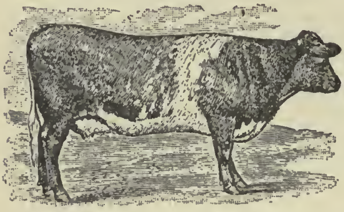


Figure 5. The net returns from Ethel, when used in the dairy, a cow bred mainly for beef, for one year, figuring butter, skim milk and feed at market prices, in 1895, was $9.92. Haecker.

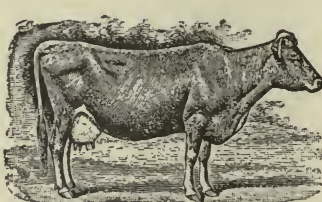


Figure 6. The net returns from Houston, a specially bred dairy cow, for one year, figuring butter, skim milk and feed at market prices in 1895, was $58.33. Haecker.

most of her food into the valuable butter fats, storing up a minimum amount in the form of protein in her milk, or as a padding of fatty tissue on her body, is the best machine for transferring a large portion of energy from the pasture or grain bin into the valuable product, butter.

The illustrations shown in Figs. 1 to 6, inclusive, may serve to show differences in engines, plants and animals as to their effectiveness in changing latent energy into active forms useful to man. They emphasize the great importance of properly understanding the relation existing between latent and active energy as related to agriculture.

The sciences related to agriculture.—The theories and facts of science have been grouped around the great divisions of nature. Thus, there is the science of plants, the science of animals, and the science of minerals. The division of knowledge into groups continues with the accumulation of facts, until there are many sciences. Some of these deal mainly with the facts without direct reference to the utility of the facts, while most sciences ultimately affect some economic interest. Agriculture has been wonderfully aided by the sciences, many of which have a very close relation to agricultural production and to the life of the farm home.

In a general way the sciences may be divided into two classes: The physical sciences, which deal with the facts and laws of matter in which life may or may not take part; and the biological sciences, which deal only with living forms, both plants and animals. Among the physical sciences the following are especially useful to agriculture: Mathematics, physics, mechanics, electricity, chemistry, geology and meteorology. Since the biological sciences treat of the life of the animal and the plant kingdoms, they are equally useful and important, for they throw light upon many things which have a practical bearing upon plant and animal production, such as heredity, variation, selection, and the development of species, varieties or breeds. Some of the more general biological sciences are botany, bacteriology, zoology, entomology and breeding.

Mathematics is the most exact of all the sciences. It deals with the measurement and relations of quantities, and by symbols and processes treats of numbers, as in arithmetic and algebra, and of space, as in geometry. Mathematics is applied to all the physical and biological sciences, and is used in all industries and professions. Like all the more practical subjects, the study of mathematics not only develops mental vigor, but also gives valuable facts.

Physics, in its specific sense, deals with the phenomena of matter, and with the energy which accompanies matter, excluding the phenomena peculiar to living matter, biology, and the phenomena peculiar to elemental forms of matter, chemistry. Physics treats of the constitution and properties of matter, of mechanics, acoustics, heat, light, electricity and magnetism. A study of the general principles of physics, illustrated at every possible point by its use in explaining mechanical contrivances, soils, feeding and other questions in agricultural practice, is proving most useful as a means of general mind-training and of acquiring useful facts.

Mechanics treats of the phenomena caused by the action of energy, or force, on material bodies. It considers the phenomena of static bodies of matter with their latent energy, and kinetic bodies with their dynamic forces operating. Applied mechanics deals with the invention, construction, care and use of all kinds of structures, machines and devices. The people of the world are housed, clothed, fed, transported and supplied with information and luxuries in far greater amount and with far less cost of time and effort because of the development of mechanics. Theoretical mathematicians and physicists by their researches, and inventors, have given the basic ideas for the development of practical mechanics. The scientist and the practical man have alike contributed to our sum of mechanical knowledge and to our collection of mechanical appliances.

Electricity deals with one form of the invisible force of inorganic and organic substances which manifests itself in many ways, and which is rendered active by some molecular disturbance, as from friction, rupture, or chemical action. The laws of the generation, storage, transportation and use of this power and the mechanical appliances driven by it furnish subject matter for school studies and laboratory practice alike practical and useful for mental training.

Chemistry is that branch of the physical sciences which treats of the minutiæ of substances, as of their atoms, their molecules, the relations these units sustain to each other within substances with simple and compound molecules and the manner in which molecules of different kinds are constructed. Theoretical chemistry deals with the laws governing chemical action, while applied chemistry treats of the relations of these laws to agriculture, medicine, mining, sanitation, etc. Physics and chemistry overlap or dovetail, as do all related sciences, and classification cannot make straight lines where nature has not made them. Classification, as in books, is only to aid us in better organizing our thoughts.

Geology treats of the constitution and structure of the earth, the operation of its physical forces, the history of its development, including the causes and modes of changes it has passed through, and the occurrence and development of organisms. It embraces physical geography in part, but is not concerned with political geography. It includes a study of the successive layers of the earth's surface, and the meaning of the fossil evidences of living things in each layer is considered. It gives the relation of the slowly developed organic life through the geological ages to the plant and animal forms now on the surface of the earth. It has very practical relations to studies of soils, farm management, and to plant and animal production, as well as to mining and many lines of engineering. The study of this subject is peculiarly broadening, in that it gives the mind a view of the development of life under a process of gradual natural evolution.

Meteorology treats of the phenomena of the atmosphere, especially those that relate to climate. This very difficult subject is slowly being brought into a form adapted to a school study, and as a practical science it is being developed so as to make weather prediction very useful.

Botany has grown to be a wonderful science. The many, many thousand species of plants are being classified and named, and the functions of the parts of plants are being worked out. New facts as to the best places and plans for growing and cultivating each useful plant, are being brought to light. Plant breeders are studying the laws of heredity, and so improving the crops of the field, garden and forest that yields are increased, and the quality of the products improved. New beauties are added to flowers and foliage; new flavors to fruits and vegetables; and new qualities to fibers and woods. New ways of propagating, cultivating and feeding plants are discovered, and the methods of harvesting, preserving and utilizing plant products in the home and in the factory are becoming so numerous as to be fairly bewildering.

The study of the life histories of fungi, such as molds, rusts and other minute plants, is doing a great deal to aid farmers in combating fungous diseases of plants and animals, and in making use of some of these minute plants for economic purposes. These plants have no flowers or seeds such as larger plants have, and usually a microscope must be used to work out their life histories.

The farmer who does not seek to learn the interesting things about plants is constantly losing a large part of the enjoyment which nature has made so abundantly available to him. Facts about plants which are available in books on botany, horticulture and agriculture, and taught in agricultural schools, are of great value to those who till the soil.

Bacteriology has brought to light a world of important facts regarding the many germs which breed disease in plant and animal bodies, which cause decay in dead organic substances, which aid in elaborating plant food from soil and air, which assist in transforming the food in the digestive canal of the animal, and in many other ways take part in plant and animal production. Bacteria and other very small organisms are so simple in their structure that it is difficult to class them with animals or plants; they are so simple that they have not the special organs or functions of either.

Zoology.—The science of animal life is full of interesting things. There is no study more profoundly interesting than that of the development of species in animals and in plants. Every species of animal has a different life history, and many of its habits, when known, are very interesting. The anatomy, or structure, and the physiology, or functional activities, of each species of wild, and especially of domesticated, animals is of interest. The experiment station officers and others are working out methods of feeding, breeding and managing live stock that are of great value to the farmer.

Entomology.—This division of zoology deals with insects and is full of interesting facts. Descriptive entomology tells of the life histories of the various insects, and the stories of the work of these wonderful little creatures are full of interesting surprises. The patient entomologists have worked out methods of combating many injurious insects and have learned that many of them are by nature our friends and should be protected. A knowledge of how to combat those that obtain their food by sucking the juice out of plants and those that chew their food is both interesting and useful to the farmer.

The agricultural sciences.—While the practice of agriculture is mainly art, agricultural science is becoming the most wonderful of sciences, in part because nearly all the other sciences contribute to agricultural science. Only recently have the facts of agricultural theory and practice been brought together in a systematically arranged form. A literature of scientific, practical agriculture is being written, most varied in kind, most wonderful in extent, most interesting in character, and most useful in its economic relations. No other science interests so many people, nor are the lives and work of any other industrial class brought so close to the laws, the forces, the materials, and the enjoyable objects of nature.

The principal subjects under which a knowledge of farming is obtained are: Agriculture, or agronomy, the study of field agriculture; horticulture, the study of garden and orchard crops; animal industry, the study of animal production; dairy industry, the study of dairy stock, dairy production and dairy manufacturing; veterinary science, the study of the diseases and hygiene of animals; breeding, the study of how to originate animals and plants with heredity which will produce higher economic and artistic values; agricultural chemistry, the study of the chemistry of soils, plants and animals; and rural engineering, the study of machines, buildings, roads, drainage, etc., relating to the farm.

Agricultural technology.—This group includes a study of manufacturing as related to agriculture, such as sugar making, slaughtering animals, manufacturing commercial fertilizers, textile manufactures, etc.

CHAPTER IV

GEOLOGICAL HISTORY OF THE EARTH

Plants and animals have developed from lower forms.—The generally accepted theory is that at one time the earth's surface was of solid rock, but the action of wind, water, glaciers, earthquakes, heat, cold and other forces, during many ages, has broken up this surface into smaller particles which form the larger part of our soil as we see it today.

Some of the lower forms of plant life which live largely from the elements of the air, at first grew upon the rocky surfaces and on the pulverized surface materials, and gradually deposited small amounts of organic matter which, together with the disintegrated soil particles, formed rich soils on which higher plants and animals could grow. As the ages passed a large growth of plants developed on the surface, and the organized matter of decaying plants, mixed with fine particles of earth, helped make a productive soil.

In many places the rains washed these plant and animal remains into streams, and, together with particles of soil, they were deposited along the river beds or deltas in layers. Where earthquakes, the washing of water or other influences have operated to expose the edges of these layers, the geologist has studied and unraveled the history of the layers of earth. Surface layers which have been formed in comparatively recent times are found to contain the fossil forms of the plants and animals now living on the earth. As he goes deeper among the older deposits, the geologist finds many lower forms of animals and plants, of some of which no living representatives have ever been found. In certain layers it is found that given kinds of animals or plants are more abundant than in others, and thus definite periods of ages are marked off in successive layers, as the Devonian age, when fish forms of life were most abundant. The Carboniferous age is marked by the enormous growth of lower forms of plants which have given us the large coal fields. But the most important of all the teachings of this wonderful history is, that our present forms of plants and animals have ascended from lower, simpler and inferior forms, and that we may expect to find this process still continuing.

All the things about us that have in no way been modified by man we call natural, and the wonderful things taught by them we call natural history. This natural history is a wonderful book and we see about us in living things and in rocks, hills and rivers its most recently written pages. One of the most interesting facts is the evidences in the layers of rock, slate, clay, etc., of the great age of our world, or the long time covered by natural history. There are several theories as to how our planet came to have the shape and size that it has, but there is much evidence that in the beginning the earth was very hot. According to this theory, part of the water now in the seas, rivers and earth was in the atmosphere as gas. As the cycles of centuries rolled on, the earth gradually became cooler. A part of the water fell on the surface. As the surface of the earth lost its heat, it would crack and part of the water would rush in, the heat being so intense as to form such volumes of steam that terrific explosions took place. As the surface cooled sufficiently, it was found that the very first forms of animal and vegetable life appeared, but the earth was not in a settled form even when these appeared, for the geologist finds in the layers of rocks of elevated regions the remains of plants and animals that have lived at the bottom of the sea. This shows that forces are at work which are continually modifying the physiography of the earth, leveling some parts and elevating other parts above their original position. The rains falling on the high places of the earth's surface washed the looser particles to the low places and with them the forms of life that then existed, thus leaving a record of the times in the fossils preserved in the layers thus formed. In some cases a deposit of earlier records has been raised and washed down a second time, and here the record is confused, for a layer of rock or clay may thus contain forms that existed centuries apart in point of time.

We think of the earth as being very stable, but crustal disturbances, as earthquakes and volcanoes, occur frequently at many parts of the globe. The formation of mountain ranges is wonderful and can be appreciated only by those who have been on the mountains and have been awed by their stupendous proportions. These mountain ranges may be accounted for, in part, by the fact that the earth is cooling from the outside toward its center, and, as it loses heat, it becomes smaller and the surface, being hard, bulges up in places and settles down in others, as does the rind of an apple when it is drying.

Development of present land surfaces.—The layers of the earth which are now exposed have been modified not only by the action of heat and cold, wind and water, but also by animals and plants. During recent geological times great changes in temperature have caused immense collections of ice, called glaciers, to lie upon and flow or glide very slowly over large areas of land near the north and south poles of the globe. These glaciers, which once pushed much farther out from the poles toward the equator than now, have done much to transport the particles of soil from place to place, mixing the stony substances together, or depositing them in layers, as the case might be. Water and winds have also done much in this mixing of soils. In moist, low places vegetation has grown and been preserved by water covering it, and thus collected into beds of peat. Peat beds thus made in former times, and afterward covered with clay, in some cases have been gradually transformed into coal.

In other places, where the surface of the earth is composed of solid rock, of hard stones, or even of gravel or sand, which does not easily decay, vegetation has not been able to grow and the surface is still bare and not hospitable to plants. Between these two extremes, where soils have been made of clay or of a mixture of clay and sand and other materials, plants have found a congenial home. The soils have an abundance of plant food; they are rich in humus or decaying vegetable matter, and, therefore, able to hold moisture, and to provide bacterial and other agencies which aid in producing conditions suitable for the feeding by the plant roots. In some places these congenial soils are formed by the rock decaying where it lies; in other places they are formed by the water washing particles from many places, thus mixing them together and spreading them out in layers ready to form the home of plants. In other places the winds bring together soil particles in a mixture which is adapted to the growth of plants.

Igneous rocks (rocks that are formed from the molten lava from the interior of the earth, or that at least have been heated) are found at many places on the surface of the earth, as where they were poured through volcanoes or oozed out through openings on the earth's crust. Sand and gravel are found in other places where they have been deposited by the action of water. All these form inhospitable soils. The granitic and other igneous rocks are not open to the penetration of plant roots, and sand and gravel are not suitable soils from which plants can secure food.

The glacial period.—Beginning tens of thousands of years ago, and continuing, perhaps, ten thousand years, a most important occurrence of vast proportions happened to the north temperate zone of the earth. At least this occurrence was important for the welfare of man in his present state, because it served as a stupendous motor to provide immense areas of finely pulverized mixed soils suited to growing valuable crops. Owing to some astronomical or geological phenomenon not well understood, the sun failed to heat this zone as had been its custom before, or as it does at present, and the climate became as cold in Maine or Minnesota as it is at the present time near the north pole. From Missouri northward in America, and in a similar zone in Eurasia, was a region of perpetual snow. The rain and snowfall of each season was added to the layer which fell the year before, and thus there gradually accumulated a sheet of snow and ice hundreds of feet thick, extending southward far into the Mississippi valley basin in America and another sheet extending into the central part of Eurasia. This sheet of accumulated snow and ice was called the great glacier. In the beginning the zone of perpetual snow of the arctic circle gradually extended southward as the cold continued to increase from age to age. The cold crept southward and extended the southern edge of the region of perpetual snow. The annual fall of ice and snow continued to accumulate and finally extended southward in the United States, as shown by the map in Figure 7, reaching to the Missouri and the Ohio rivers. It is not thought that this movement took place rapidly or even regularly, as during some ages the cold would increase more rapidly than at other times, then again, the cold would not increase but would even decrease.

The snow and rain accumulations had become pressed into a solid sheet of ice, hundreds and even thousands of feet in thickness. We would expect that this ice would lie quietly on the surface of the earth, but it is found that ice will flow to a lower level, as will water, though very slowly. This fact is illustrated by pressing a chunk of ice in a very strong box which it does not quite fit. By placing an immense pressure on the chunk, it will gradually bend or mold itself to fit into all the corners of the box without apparently breaking, thus illustrating that under heavy pressure ice will flow like a liquid, moving, of course, only very slowly. That great sheets of ice do actually move, or flow, is shown by the great ice sheets now known to be moving down the valleys in Greenland and the Alps, and in other regions of perpetual snow. In Greenland the ice is shoved out over the water, and there the weight, assisted somewhat by the waves of the ocean, causes great pieces of the ice sheet to break off, which float out into the ocean as icebergs. It is even found that ice flows faster in the center of its path down the valleys than it does near the edges, just as water flows more rapidly in the center of the river than where it is retarded by coming in contact with the shore or bottom.

The states north of the Missouri and the Ohio rivers were practically all covered by the great glacier. The Mississippi valley was then much as it is now, the elevated plains toward the Rocky Mountains preventing the ice sheet from flowing in that direction. The higher land at the foot of the Alleghanies also prevented the ice sheet from flowing over against those mountains. There were, also, other occasional higher portions of the earth, as around the west end of Lake Superior, and in the vicinity of Dubuque, Iowa, where the glacier did not flow over the land. There was stored up in this immense sheet of ice a large amount of water, which, during the period of melting and recession of the yet moving south edge of the glacier, was added to the annual rainfall and greatly enlarged the streams flowing into the Mississippi river, and the drainage of this whole region was very different from what we see at present. Now only a part of the annual rainfall must find its way to the Gulf of Mexico. This excess of water during the recession of the glacier is illustrated by a spring rain melting the snow, combining the rain and the snow water into a flood. The front edge of the glacier, instead of being a straight line, was very irregular. Great streams, or fingers, of ice flowed south through the valleys and lower areas, in advance of the general body of the glacier. The recession was sufficiently rapid, in spite of the slow forward movement of the frozen water, so that the ice which flowed to a given point, and there melted, added an immense amount of water to the usual rainfall. All this water swelled the streams in the midsummer so that, instead of the small streams winding through the flats in our valleys, there were rushing torrents rising nearly to the tops of the present bluffs, which were then banks of the large streams.

Many neighborhoods in the states mentioned have very interesting illustrations of how the glacier and the large volume of water from the melting glacier operated in modifying the land surface. Every citizen of such regions should study the glacial geology so as to be able, by observation, to understand the phenomena presented by the surface features in his own neighborhood.

Glacial drift or till.—Prior to the time of the glacier there was loose soil, rock, sand, clay, etc., covering the underlying rocks of the region over which the glacier flowed. The ice, in flowing over this surface, gathered up much of the loose clay, sand and stones, and also tore loose and ground up more of the underlying rocks. This whole mass was made finer by the immense forces in operation, and when the ice melted this material was deposited along the margin of the glacier. Where the recession of the ice sheet was gradual, the debris was laid out in rather level sheets over the surface of the earth and is now called by the geologists drift or till. In some places this material still lies as it was deposited, with fine and coarse particles mixed, but in many places the water flowing from the melting glacier washed the drift about, often making great valleys through which the streams could run. The material which was thus washed about by the water, was usually left assorted and in layers, just as the stream on the hillside carries forward gravel and small stones, particles of sand and clay, depositing the heaviest particles first. The finer particles of clay and silt are often carried long distances before they are deposited in the quiet waters of some lake or large stream. Since the fine particles were carried out in the water beyond where the coarser particles were deposited, the clay is usually found above the stones, gravel and sand.

The formation of morainic hills.—In some instances, owing to temporary cessation in the increasing warmth, the glacier, instead of receding with regularity, stopped for a time, or even again progressed for a period. The melting taking place only as rapidly as the ice flow proceeded, in case the front edge of the glacier remained stationary, there was naturally much debris left in the place where the ice melted, for the ice always carried within its body stones and finer particles of earth. In this way ranges of hills were formed. These are called moraines, of which there is an example in southwestern Minnesota, called the Coteau Hills, and many others in the states over which the glacier flowed.

Unassorted till formed good soils.—Where the glacier dropped its debris in such a way that we find no distinct laminæ or layers, the geologists call it "till," or "unassorted till." Where water flowing from the melting ice washed the loose materials about and deposited them in layers of clay, silt, sand, gravel, etc., the geologists call it "assorted till." Some of the best soils are those where the glacial till is unassorted. The farmers of the middle northwest have the great glacier to thank for mixing together clay, sand and particles of all kinds of rocks, thus making soils wonderfully adapted to the growth of useful plants. These soils of mixed materials furnish ideal mechanical conditions for the roots of plants, contain the needed variety of mineral plant food, conserve the remains of plant or animal life as organic fertilizers, favor the elaboration and storage of plant food as well as the absorption and conservation of soil moisture, serve as hospitable homes to useful soil bacteria, and are easily handled with cultivating implements.

Assorted till formed poor soils.—Wherever the water assorted the great body of materials drifted along by the glacier, some poor soils are found. Layers of sand left at the surface give us sandy soils, likewise layers of gravel or of boulders make very poor soil, and even layers of dense clay without a mixture of sand are less valuable than soils made up of these materials mixed. Sandy soils in the regions of ample rainfall have, in many instances, been so covered with vegetation and so filled with decaying organic substances, that they retain water very well and nourish large crops. Even gravelly soils, where moisture is abundant, are gradually so changed that they raise crops of native plants and make fair agricultural soils. Clay soils which are too dense to make very good water reservoirs, or to allow the entrance of air, are, likewise, sometimes made into very productive soils by the plants which grow on them. These clay soils, in some cases, cover large areas. In the valley of the Red River of the North is an example. The glacial ice melting in "Ancient Lake Agassiz" (see

Figure 7), which extended from the south border of the receding glacier above Winnipeg, Canada, to the region of Lake Traverse on the western side of Minnesota, where it had its outlet through what is now called the Minnesota river, deposited in its basin a final surface layer of fine clay, covering what is now known as the valley of the Red River of the North. Clay soils, thus laid, have their good qualities and their disadvantages, as compared with the best types of mixed soils.

An undulating country.—The drift formed a generally undulating surface over the upper Mississippi valley region, the flood waters having eroded hollows, giving natural surface drainage; and the gentler forces acting through the long ages since the glacial period have rounded down any steeply washed banks, making the country one of beautiful broad hills and vales. The great prairies of the West resemble the swells of a high sea, with the waves and troughs much enlarged.

In digging into the drift, as in making wells, layers of clay, sand, gravel and unassorted till are met with. Sometimes these seem to have been deposited in an unnatural order, or lie in two or more series of layers. In some places glacial streams have eroded large masses of the drift, and, carrying it forward, left it in assorted layers. Too often sandy or gravelly layers have been left at the surface, and form poor soils and subsoils. In other cases the unassorted till forming the surface contains bowlders, which are an impediment to cultivation. There are areas within the glacial region over which the glacier did not flow; some are covered with soils formed from easily decaying rocks, or, as north of Lake Superior and in mountainous regions, are of granite, trap rock or sand rock uncovered with soil; others were formed as clay layers and rock ledges. The forces still acting on the soil cause it to become more productive; the action of water, of bacteria, of plant roots and of air on the soil are all of great interest and lead in a most interesting way to the study of plants; likewise of animals and men which depend upon the food the plants obtain from the soil and air.

Source of materials moved by glaciers.—The source of material moved by the glacier is difficult to determine. Doubtless in the beginning of things, when the earth's crust first became cool, it was much like the lava which now flows from the craters of volcanoes. This glassy, hard, rocky substance was not made up like marble or limestone or slate, but elements of all kinds of rocks were melted together in one mass. This rocky crust was broken up by the water, air, sun and winds, literally rotted, and thus made into soil; and later, as the earth became cooler, ice became one of the greatest factors in soil making, as seen in the immense grinding done by the glaciers we have been considering. During the earlier geologic periods, doubtless even the interior heat helped to break up the material of the earth's crust. Water, running into fissures of the earth and coming in contact with the heated inner part, formed such volumes of steam as to cause great explosions, throwing about and breaking up great masses of materials. We have, in more recent times, illustrations of volcanic action; one, for instance, when Vesuvius belched forth enough ashes to completely bury the city of Pompeii, and, again, more recently, on the island of Martinique.

Some of the materials of the great area of glacial drift have doubtless been transported many hundreds of miles. Many of the bowlders and other rocks found in Minnesota can be traced to beds of similar materials far to the northward in Canada. One of the proofs of the glacial action is the fact that the glacier flowed southward and carried down from the north many large fragments of the rocks over which it passed, as well as much of the finely pulverized materials. Usually these coarser materials were taken from less than a hundred miles; however, geologists believe that in Europe, as in America, some materials can be identified as belonging to ledges five or six hundred miles northward. The southern two-fifths of Minnesota, or that part south of the line drawn east and west through St. Cloud, Minnesota, is an area where the surface is made up of bowlder clay, more technically called "till," into which is mixed clay, sand, gravel and stones. This same kind of excellent soil-making material was left on the surface through Iowa and as far as the glacier proceeded into Missouri, through eastern Dakota, Nebraska, Illinois, Wisconsin and other states eastward adjoining the Great Lakes over which the great glacier moved. Northeast of St. Cloud, Minnesota, there is not such a happy mixture, and the soils are assorted, sand, gravel and clay often appearing in separate areas.

Soils formed in place.—Only in the northern states, however, do we find these mixed soils of glacial origin. In most districts, as in the southern part of the United States, the soils have been formed *in situ* (in place). In the Piedmont Plateau region of the South Atlantic states the soil is the remains of rocks which have gradually decayed, only those particles remaining to form the soil which longest resisted decay. In some cases a limestone rock has decayed, leaving a limestone soil; in other cases a granite rock has rotted, the more soluble particles being washed out, leaving particles forming a granitic soil. In some places more than one layer of rock has been dissolved, the remains of the upper rock being mixed with the remains of the lower layer. In many cases the fine particles resulting from this soil weathering have been mixed by the agency of water and wind, especially in the lower places, resulting in a mixed soil, or more frequently in a stratified soil. In case of young soils, as where rocks have recently been ground fine by glacial action, the broken particles of sand have sharp, harsh edges. Where this sand has been much worn, as in running water, or in sand dunes often shifted by the winds, the particles become rounded. In case of soils formed *in situ*, resulting from very long continued action of the elements, the particles are not so angular and firm. Like ripened cheese, they have lost their toughness as well as their rough edges.

Some interesting glacial geology: History of the Falls of St. Anthony.—A very interesting chapter in the history of the glacial period, illustrating the magnitude of the changes wrought by geologic forces, is recorded in Minnesota. It includes the Falls of St. Anthony, the Mississippi and the Minnesota rivers and their watershed in Minnesota; also the valley of the Red River of the North, or the bed of the "Ancient Lake Agassiz," all of which tell part of the story.

The valley, from bluff to bluff, of the Minnesota river, is considerably larger than the valley of the Mississippi at their confluence, as illustrated in Figures 8 and 9. This is evidence that when the glacier was rapidly melting, while its southern boundary was passing from northern Minnesota, the Minnesota river was much larger than the Mississippi, and that a much larger volume of water was passing through these rivers than later, when only the present watersheds furnished the surplus rainfall to be drained off.

The Ancient Lake Agassiz.—While the southern line of the glacier was receding northward toward the region of Hudson Bay, there was a lake in the valley of the present Red River of the North, as shown in Figure 7. This lake has recently been named "Ancient Lake Agassiz." The land slopes to the north in that valley, but the ice sheet as it receded northward served as a dam to the waters, and this so-called "Ancient Lake Agassiz" had its outlet to the southward where the Red

River of the North and the Minnesota river now have their sources. As the Minnesota river extended westward from where it and the Mississippi river came together, it received, during that period, the waters from a very much longer section of the southern edge of the glacier than did the Mississippi river. The watershed of the Minnesota river during that time extended far out

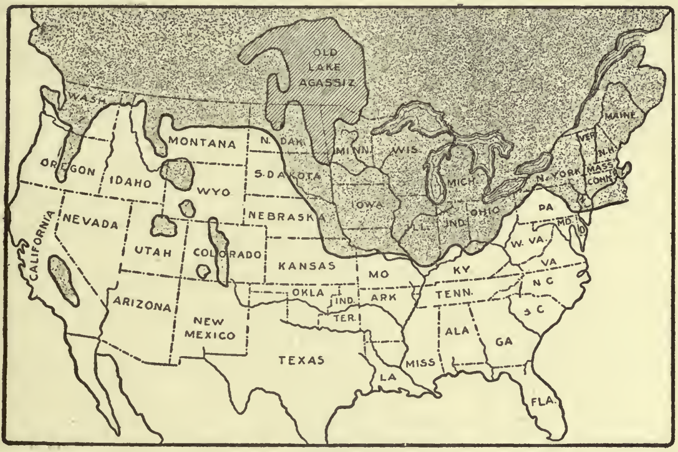


Figure 7. The dotted surface, including the system of great lakes, and the area marked "Lake Agassiz," shows the area covered by the great glacier during the period when arctic cold extended far down into the temperate zone. The waters from the melting glacier and from the annual rainfall flowed from the southern arm of Lake Agassiz into the Minnesota river.

into North Dakota, into the northwest territories of Canada, and even around eastward to the north of the Mississippi river. In other words, "Ancient Lake Agassiz," received water from streams flowing into it from the east and from the west as well as from the surface of the receding glaciers. The larger watershed, supplying a larger flow of water in the Minnesota than was supplied to the Mississippi river during the glacial period, seems to account for the washing out of the larger valley of the first named river; but this is not the most interesting fact. (Figures 10 and 11.)

As long as the original larger bed of the Minnesota river was well filled with water at Fort Snelling, where the two rivers come together, the water from the Mississippi did not fall over a precipice, but flowed gently into a body of water nearly as high as its own river bed, as shown in Figure 11. When the ice dam in the vicinity of Lake Winnipeg was melted low enough for the water from "Ancient Lake Agassiz" to flow over it, and thus drain the water of that lake to the northward into Hudson Bay, instead of to the southward into the Gulf of Mexico, the Minnesota river no longer received water from the watershed of the valley of the Red River of the North and from the melting glacier, but only that falling in its own valley, extending from Big Stone Lake on the west border of Minnesota to where St. Paul, Minnesota, now stands. This caused the great reduction mentioned in the volume of the water in the Minnesota river; it no longer had as large a watershed as the Mississippi, which

Figure 8 shows in cross-section the Minnesota river above where it and the Mississippi come together. This river is a type of the common rivers made in the glacial period. From A to B was the surface of the flood water in the glacial times when the melting water from the glacier added to that from the annual precipitation of rain required a large channel. From C to D is the present surface of the water, ordinarily forming but a small river. In the seasons of high water, as at the time of spring floods, the water rises so as to cover the bottoms from E to F.

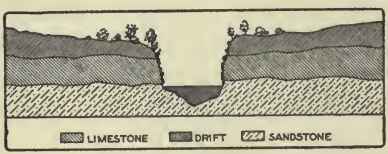


Figure 9 shows a cross-section of the Mississippi river above where the Minnesota enters it, but below the Falls of St. Anthony. This river at one time carried much more water than now; but, as shown by the width between the bluffs, it never contained as much water as the Minnesota river did during the recession of the great glacier, as shown in Figure 8.

extends from St. Paul north to Lake Itasca, and is broader than the watershed of the Minnesota; and hence the Minnesota changed from much the larger river to the smaller one.

The recession of the Falls of St. Anthony.—The waters of the Mississippi now had to fall over a precipice, as shown at D, Figure 12, to get down to the deep bed of the Minnesota River, where it had previously flowed directly out into the waters which filled the original

Figure 10. The area inclosed by the line thus —..—..—..—.. is the area formerly drained by the Minnesota river. The area at present drained by the same river is surrounded by the solid line, thus ————. The area then, as now, drained by the Mississippi river above where the two rivers flow together is inclosed by a broken line, thus - - - - - - - -

banks of the Minnesota, as shown in B, Figure 11. At this time and in this way the Falls of St. Anthony were formed. The water fell over a ledge of limestone rock which is underlaid with a very thick stratum of loosely cemented sandstone, that is easily worn away by the falling water. The waterfall thus gradually undermined the overlying limestone, which broke off in large masses and was washed away. Thus the falls had receded northwestward about six miles to within a few hundred feet of the present site, when they were first discovered by the European explorers, and named the Falls of St. Anthony. From comparisons of descriptions and drawings made by the earliest explorers, and pictures taken at later dates, it seems that these falls receded at the rate of several feet per year, or that the falls receded eight miles in about seven or eight thousand years. This has been thought by some to very roughly mark the date when the glacial dam was melted low enough to allow the waters of the valley of the Red River of the North, then the "Ancient Lake Agassiz," to flow northward into the Hudson Bay and no longer swell the banks of the Minnesota River, which began to shrink to a small stream in the bed of the old river.

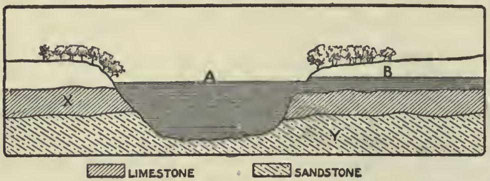


Figure 11. A, surface of water in the Minnesota river in glacial times when it received the water from the valley of the present Red River of the North. B, surface of the water in the Mississippi river in glacial times when it flowed gently into the well-filled channel of the Minnesota river. X, the limestone. Y, the layer of sandstone below.

In 1871 it was found that the Falls of St. Anthony, beside which a number of flour and saw mills had been erected, were in danger of being undermined and washed out. The water had broken through crevices in the lime rock, which was thin, and was wearing away the soft sandstone beneath. As this would have caused the falls to recede very rapidly, and to become a mere rapids, destroying the valuable water power, the United States

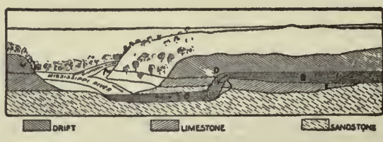


Figure 12. The Falls of St. Anthony when its recession had just begun. A, water in the Minnesota, after it had ceased to receive the glacial water. B, water in the Mississippi river above the falls. C, water in the Mississippi river below the falls. D, the Falls of St. Anthony when yet at a point near the confluence of the two rivers.

government put in a solid wall of masonry and an apron to preserve the falls, not in their picturesque form, but so as to conserve the water power. (See E in Figure 13.)

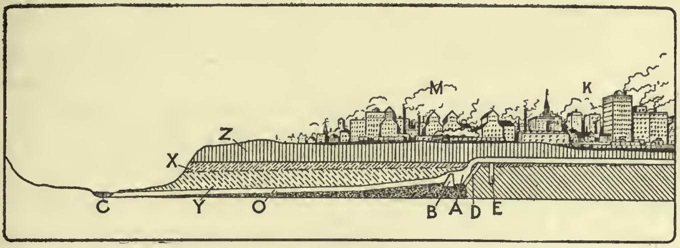


Figure 13. The Mississippi river. A, Falls of St. Anthony. B, dam below the falls. C, the Minnesota river at the confluence of the two rivers. D, apron to prevent the falls from further receding. E, retaining wall above the falls. K, the present city of Minneapolis. M, the group of great flouring mills. O, river below dam. Z, drift above the limestone. X, limestone. Y, sandstone.

In 1896 a dam was built in the rapids a short distance below the falls, for added power to be obtained. (See B, Figure 13.) As the Mississippi river descends quite rapidly between the great falls and the confluence of the two rivers, there is room between the high bluffs for other dams which are being erected.

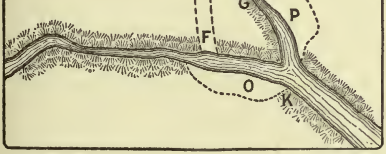


Figure 14. A diagrammatic map showing how the water in flood times, during the glacial period, flowed around the higher land at X, X, following the flood course of F, F, F, and entered through a branch stream into the river at K below the present gorge from G to G. No doubt there was once a falls that gradually receded from G to G, as the water pouring over the limestone layer of rock disintegrated the soft sandstone underneath it and undermined the thin limestone. At the confluence of the two flood streams a great gravel bed was formed at O from the materials washed out through the floodway at F-F. Another gravel bed was formed, possibly at a later date, at P.

In Figure 12 is a diagram showing the recession of the Falls of St. Anthony very soon after the recession began. In Figure 13 is a diagram showing the falls at the present time, also the mills for which they furnish power. Minnehaha

Falls, made famous by Longfellow's poem, are in a stream, Minnehaha creek, which flows from beautiful Lake Minnetonka and enters the Mississippi river about one-fourth of the way from the mouth of the Minnesota river to the Falls of St. Anthony. Minnehaha Falls did not begin to form until the Falls of St. Anthony had receded past the mouth of Minnehaha creek, when the creek waters began to tumble into the deepened bed of the Mississippi river. Minnehaha Falls, like the Falls of St. Anthony, have since then gradually receded, by the waters mining into the very loosely coherent sandstone from beneath the ledge of limestone, causing it to break off, thus wearing away a gorge nearly a fourth of a mile long, at the upper end of which is Minnehaha Falls, the Indian name for laughing water. In Figures 14, 15 and 16 is shown one of the slow but mighty changes wrought by water acting through many centuries. There is evidence that the two rivers which now flow together at K formerly had their confluence across the line, F, F, F, at least in flood seasons. The north river gradually cut the soft rock out of its east branch, forming a gorge at G, G, and it no longer flows across F, F, F, even in flood seasons. A very small stream now follows F, F, F.

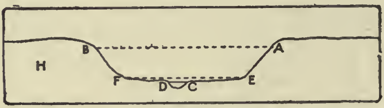
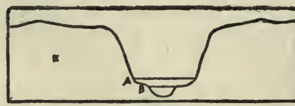


Figure 15. The broader valley of the glacial river where it was cut through the loose till, as above the gorge G-G in Figure 14, during glacial times. A-B, surface of flood water in glacial times. E-F, flood water covering the present valley. C-D, present stream bed.


In Figure 16 is shown a cross-section of a river where the glacial floods cut through limestone and sandstone, forming the gorge at G-G in Figure 14. Here no broad valley is found on either side of the present stream. At first this seemed very strange, since both farther up the stream, as above F, and farther down, as below F, the waterway had been cut out broader by the glacial water. Upon further inspection evidence was found that most of the flood water during glacial times had passed around the higher land underlaid with rock, as shown in Figure 14. A, water at flood. B, water when no flood is on.

CHAPTER V

THE SOIL AND SOIL FORMATION

The soil is that part of the earth's surface into which the roots of plants penetrate. We often speak, in a narrower sense, of the soil as that part of the earth which we handle with tillage implements. The term "furrow-slice" refers to that rather definite zone of soil which is inverted by the moldboard, disk plow or the garden spade in preparing the surface of the land for cultivation. "Subsoil" refers to that part of the soil below the furrow-slice. The terms "dust blanket" and "dirt mulch" are often used to indicate that upper portion of the furrow-slice which is kept open and mellow, as by intercultural tillage, that the soil moisture may not readily rise quite to the surface by capillary action, but be stopped before it reaches the surface where it would be readily evaporated. The term "furrow pan" is sometimes used to designate a layer at the top of the subsoil, made by the compacting of the horses' feet and the plowshare on the bottom of the furrow.

The soil is usually made up of a framework of more or less finely divided mineral particles, of partially decayed inorganic particles, of water, of air, of small quantities of soluble substances, and of bacteria and other low forms of life. In some cases, as peaty soils, the body of the soil solids is decaying organic matter, and in rare cases soils are mainly water. Most plants prefer to live in soils composed mainly of stony particles, with only sufficient water to partially fill the interstices, giving room for considerable air. Some plants prefer a soil so saturated with water that the air is excluded. Still other plants like best to have a saturated peaty soil, and some species thrive with their roots in standing or running water. Yet other plants have become accustomed to very dry soils, in which there is but little capillary water; and some even live by securing water mainly from the air.

Soil formation.—The body of most soils consists of rocky particles resulting from the action of changes in temperature, and of sunlight, water, winds, ice, plants, animals, man and other agencies on the rocky covering of the earth's surface. In most places there has gradually accumulated above the rocky crust of the earth a layer, many feet in depth, of more or less finely divided mineral materials, and our present soils have been a long time in reaching a condition suitable for growing crops. In other cases the layer of pulverized material, coarse or fine, or coarse and fine mixed, but thinly covers the underlying rocks, or the solid rock remains uncovered. Minute plants, as bacteria, lichens and mosses, and finally grasses and larger plants, develop in or on exposed masses of mixed minerals, and a soil with decaying vegetable matter is formed which provides a home hospitable to most of the flowering plants.

Soils differ as to the size of the particles of which they are composed and as to the arrangement or mixture of these particles. The finest soils are clays made up of very fine particles which are closely knit together. Silt soils are not so fine nor are the particles of a nature to adhere so closely to each other. Fine sandy soils, medium sandy soils, coarse sandy soils and gravelly soils, are grades in which the particles become coarser and coarser, with less and less power to adhere closely to each other. Clay, silt, sand, gravel and stones may be mixed together in all kinds of proportions. Any mixture of clay or silt and sand which combines the adhesiveness of clay or silt with some of the open crumbly character of sand makes a good medium soil, which allows water to enter, holds to the water as against either seepage or evaporation, conserves fertility, and yet allows the roots of crops to penetrate easily and supplies them with that combination of water, air and plant food which makes them thrive. Any reasonable proportion of the coarser and finer particles, as one-fourth clay and three-fourths sand, or three-fourths clay and one-fourth sand, provides good physical conditions for crops. Soils arising from many kinds of rocks, the particles mixed by various agencies in varying proportions and reassorted into layers, are of many types. The various sizes of particles, the substances of which the particles from different rocks are composed, the proportion of organic matter and other characters, enable soils to be classified in rather definite groups.

Whitney of the Bureau of Soils of the United States Department of Agriculture, under whom soil surveys of many counties have been made, has classified the soils of the country under several hundred types, and expects to add still more types. This is an artificial classification made for convenience in mapping soils and in studying farm management, and is necessarily less definite than the classifications that botanists and zoologists have made of plants and animals. Living organisms have had the living force of heredity plus the inorganic forces to develop natural grouping, while soils have been grouped by the common physical forces alone.

Areas of types of soils.—The elevation and depression of the earth's crust, causing the shifting of seas and changes in the direction of the flow of streams; the flowing of surface waters; the action of winds, glaciers and other agencies, have in one place made mixed soils and in another soils of only one kind or size of materials. Some soils are thus very simple and others very complex.

These soil areas, whether formed *in situ* of the least easily decayed rock substance; in homogeneous layers, as of clay or sand assorted and deposited by some agency; or composed of mixed materials, as a bowlder clay or a sandy clay, are in areas irregular in outline, and usually much overlapped and mixed. A general soil survey of any locality, outlining the extent of its soil types and mapping each area under an appropriate name, gives a basis for studying the need of each soil area and for developing good cultural systems suited to it. Following the soil survey naturally come the fertilizer and crop rotation surveys, and the general farm management survey for determining, by systematic field plot tests on each soil type, the fertilizers needed, also the kinds of rotation and systems of farm management which best maintain high productivity and are permanently the most profitable.

All the activities breaking up the surface of the earth's crust, mixing and piling some materials here, assorting and spreading others there, leaving the underlying rocks deeply buried in one place and uncovered in another, have given to one section good materials for soils and left another a barren waste of rock or a desert of sand. The surface of mixed material forming loose earth, mainly sand and clay, is rapidly changed into a productive soil. On the other hand, the changing of inhospitable lava beds, the transformation of the dense clay recently risen from the lake, the binding and bettering of the drifting sand surface, or the filling up of a gravel bed and making it into a hospitable soil, have all taken ages of time, even under the many forces at work.

Agencies in soil formation.—The physical agencies—air, sun, wind, water and ice, heat and cold—are in some cases sufficient to crumble the lava. Spores of minute lichens fall upon hard rock, germinate and form small plants. These live mostly upon moisture and air, obtaining some food from the dust and soil particles continually being brought forward from adjacent soil areas. Where the small plant comes in contact with granite or other rock, it secures minute quantities of mineral food. One lichen plant living and decaying makes it possible for others to grow. These, decaying on some rock surface and lodging in some crevice, result in an accumulation of vegetable matter and make a soil habitable for more highly organized bodies, as mosses. The mosses, in their turn, gathering into their branches more or less particles of crumbled rock and other material driven by the wind or carried by the water, decay, adding humus to the soil, and finally make a place suitable for the germination of seeds and a feeding ground for roots of some of the more highly organized plants. Thus it is possible for the most inhospitable surfaces to be made more or less productive. It is quite possible that bacteria came before lichens and acted as soil-forming agents before the latter plants were evolved.

Soil formation under difficulties.—In gravel beds the processes of disintegration and soil building have been similar to those of solid rock surfaces. Small plants that can exist in unfavorable conditions must grow first. Their decaying bodies make it easier for the next generation, or for higher plants, and the soil is gradually enriched. If moisture is abundant in gravel beds, the surface of the land is gradually filled with lichens, mosses, and other simple plant organisms; and finally, flowering plants find in the gravel hospitable nooks for a few roots, where decaying plant materials hold moisture and plant food for their use. Even where the gravel is so large as to be called stones or bowlders, the mosses and other plants have found an abode, and the result has been that some of these soils have been so filled up with decaying mosses and other plants that they are now covered with groves of large trees. In the dry season of 1894, the forest fires in places burned away forests in the Great Lakes region, and even burned the mosses and other vegetable materials, so that in some bowlder soils one could see a foot or more down among the bowlders. Thus was destroyed in a day a forest-bearing soil which nature had required many centuries to build.

In some places vast tracts of land are covered with sand, and furnish most difficult conditions for vegetation to start. In case these sandy soils lie many feet above the supply of underground water and are so dry that plants cannot get their roots down to the moisture, nature covers them with vegetation only with great difficulty. The minute lichens, or even large plants, have trouble here in securing a foothold, for the sand is shifted about by the wind, and, in some cases, the shifting is so regular that plants can never be produced by nature in quantity to bind the sand into a soil and thus cover it with a blanket of vegetation for protection. Where the moisture is near the surface of the sand, as where water seeps out through a hillside, or where clay lies near the surface, or where the sand is near water which passes back under it, plants can get their roots into this water and more quickly fill the soil with decaying plant roots and other materials to protect them from the winds. Thus some sandy lands lying high and dry, shift before the wind and are never covered with vegetation, while others that seem equally sandy at the surface, but contain water within reach, are covered with a luxuriant growth.

Soil formation on moorlands.—Where water lies on flat areas and keeps roots and stems of mosses and other plants from decaying, there is formed a layer of partially decayed vegetable matter, called peat, or peaty soils. The strangest place, however, for soil formation is on the surface of the water, on ponds and lakes, where peat is formed by the growth of moss and higher plants resting on the water. Many places are to be found where peat a few inches to many feet in thickness covers, or partially covers, areas of very moist land, and even of lakes. In some cases, even where the peaty substances are thick, sand and clay have been washed in from adjacent hillsides, and have been arranged in layers with the peat, or have been intimately mixed with it, and thus a soil of mixed vegetable and mineral matter is formed.

Soil formation under favorable conditions.—Soil formation on clay takes place more rapidly than on the kinds of land above mentioned. Here the consistency or texture of the land allows the entrance of both air and water to the roots of the plants, and provides favorable conditions for the germination of seeds of the higher forms of plant life. Here, too, lichens and mosses were doubtless useful. In this soil their pioneer work in preparing it for the higher flowering plants naturally would be more rapid, or possibly in many cases unnecessary. The higher plants in turn would send their roots into the soil, opening up the clay and letting in more air and water, thus helping to draw off the excess of moisture, producing that mixture of air, water and soil particles best adapted to the plants which we grow in arable lands.

The glacial mixtures of sand and clay, the alluvial soils formed by running water, also the soils of mixed sand and clay formed *in situ* from decaying rocks, were even more easily formed into rich soils. Here the lichens and mosses and the other small plants following them could easily get hold and find at once conditions of moisture, aeration and mineral plant food suited to their growth. The larger plants here find many conditions favorable to their growth, and the elaboration of plant food and its supply is provided in the manner best suited to the plants. It was on this kind of soil that the greatest variety of natural crops first learned to grow. Here plants flourished and sent many roots into the soil. The decaying of both tops and roots furnished humus which, mixed with the rock substances, rapidly formed a great abundance of fertile soil. This made a congenial soil for many of the clovers and other wild leguminosæ: the class of plants which have the power to extract from the air quantities of nitrogen, which, stored in the roots, stems and leaves, further enriches the soil.

Sustaining soil fertility.—The soils that are built up of a mixture of clay, sand, gravel and stones usually afford superior conditions for the permanent growth of large crops. It is on these soils that it is possible from generation to generation to increase rather than to decrease the productivity of the land by scientific field management. It is our duty, not only to keep lands up to their virgin fertility, but to increase their crop-producing powers, so that future generations may have a richer heritage than we had. To do this, we can raise large crops and either leave a part of them on the fields, or, having taken them to the barn as feed for our animals, return the greater part of their substance in the form of manure, to the soil, so as to keep up a supply of vegetable matter. We can also use more artificial means of keeping up the productivity of the soil, as by commercial fertilizers. By allowing animals to take toll from the annual crop produced, and yet return the larger percentage of the organic matter, we can gradually increase the crop-producing power of most soils, but often we may use commercial fertilizers also to greatly increase the yields.

The soil a complex bank.—In a new bank, the money deposited in excess of that withdrawn, is a simple form of capital. As this excess is loaned and the interest earnings minus the cost of running the bank is added, the form of the capital becomes more complex. When some of the loans result unfavorably, the books are complicated by records of uncollected interest, mortgage foreclosures, property rentals on real estate, charges to the loss account, uncollected rental charges, etc. Rumors of the insolvency of the leading owners of the bank, of unreliability of the bank officers, and even defalcation, may prejudice the minds of the public against the bank, causing a falling off of the business, or even may result in a run on the bank. The business thus becomes very complex, and some very minor matter, as a true or untrue rumor as to the solvency of the banks in the town, or of the bank in question, may cause the bank to decline.

A soil is a far more complex store of wealth than a bank. Its original capital is more indestructible, but its ability to pay dividends rests on even more contingencies than in the case of the ordinary bank. Even where plants can draw upon the soil for all the mineral matter they need without seriously reducing the amount yearly made available, other conditions may determine the yields of crops. Recent investigations indicate that some soils are made infertile by very minute quantities of substances poisonous to the plants. At first this seems very strange, but a simple example from practices in fish culture will illustrate how minute quantities of poisons in solutions will act on living things. In a certain fish hatchery the water, as it runs from a spring into the troughs where the little fish are kept, becomes filled with a minute green plant called an alga. A barrel of water containing sulphate of copper is placed beside the spring, and from it a sufficient amount of this copper solution is allowed to drip to give it a strength of one part in 5,000,000, or one fifty-thousandth part of one per cent. This strength of solution has been found strong enough to kill the alga without injury to the fish, while a solution a few times as strong would cause the fish to thrive so poorly as to cause loss rather than gain from their culture.

Those who have given this matter most study believe that, in respect to many plants, minute amounts of substances poisonous to them or to certain other plants, are either given off by their roots, yielded by their decaying products or supplied by bacteria associated with their roots; while, as in the case of the fish, there are still other plants which they do not affect. As the reputation for honesty or dishonesty of the manager of a savings bank may cause the institution to prosper or decline, so it is believed those minute substances often cause profit or loss from the fields. This theory has not as yet been placed wholly in harmony with the generally accepted theory as to the function of manures and commercial fertilizers as so much available plant food added to the soil. Presumably when more is known of the soil and how plants feed, both the old and the new theories will be brought into harmony. The fact that wheat does well after corn, but often does not yield so well after wheat or oats, and that crop rotation often increases the production of all the crops in the rotation over a long series of years, cannot be so fully explained as by accepting the theory of toxic soil substances, along with the theory of the stimulation of the crops by feeding them with yard manure or commercial fertilizers.

With the peaty soils there is an over-abundance of vegetable matter. The question with these soils often is, how to enrich them in mineral substances. Care must be taken to prevent peaty soil from being burned too deeply, since once the surplus water is drained out of peaty lands, they become dry and will burn if set on fire, so that great holes or pits are often left, making the surface very uneven. This is of especial importance in regions where drouths occur of sufficient duration to allow the peat to dry out to considerable depth.

Soil body and soil fertility.—The solid body, or framework, of the soil usually makes up 90 per cent, or more, of the weight, and is composed of the solid particles of clay, sand and stone from which the soil was made. Spillman says:

"In order to understand the methods necessary for restoring worn-out soils, let us consider what occurs in a fertile soil that is growing a large crop. Imagine a cubic inch of ordinary field soil magnified into a cubic mile. It would then present very much the appearance of a mass of rocks varying from the size of a pea to masses several feet in diameter. Scattered among these rock masses would be many pieces of decaying plant roots and other organic matter, resembling rotting logs in a mass of stones and gravel. The masses of organic matter would be found to contain large quantities of water, and to somewhat resemble wet sponges, while every mass of rock would have a layer of water covering its surface. The open spaces between the solid masses would be filled with air.

"If a crop were growing on this soil, its roots would be found threading their way among the masses of rock and decaying roots, and pushing these aside by the pressure exerted by the growing root. From the surface of the growing root, near its tip, root hairs extend into the open spaces and suck up the water covering the rock particles. The plant food is dissolved in this water, but is usually present in exceedingly small quantities. While the plant is growing, a constant stream of water flows up through it and evaporates at its leaves. For every pound of growth in dry matter made by the plant, from 300 to 800 pounds of water flow up through it."

Substances used by plants.—Plants take from the soil and require for their growth and development the following elements: Potassium, phosphorus, nitrogen, iron, calcium, magnesium, sulphur and chlorine. These elements, together with carbon, hydrogen and oxygen, which may be considered as derived in some form from the air, are absolutely necessary for the growth of all higher plants. In the absence of any one of these elements none of the higher plants can reach maturity. Other elements, such as silicon, sodium and aluminum, are also invariably present in plants, but they are not necessary, as shown by accurate experiments. Besides these, such elements as titanium, copper, manganese and others have also been found, but their presence seems to be accidental; that is, they have been taken up because they happened to be present in the soil where the plants grew, thus making it impossible for the plants to reject them when they occur in solution in the soil water. It must be understood, of course, that plants do not take up these elements as such, but find them in the soil in combination with other substances. For example, calcium is not taken up in its elementary form, but occurs in the soil, combined with nitrogen and oxygen, as calcium nitrate, and as such may be taken up. It also occurs in many other compounds.

The food material which the plant takes from the soil forms only a small per cent of its weight, as shown by the percentage of ash found on burning. The amount varies, according to the plant, between, approximately, 1 per cent and 10 per cent. The bulk of the plant is made up of the elements derived from the air and water —carbon, hydrogen and oxygen. The cell walls, starches, sugars, organic acids, etc., are composed almost exclusively of these three elements; while certain other compounds like proteids, as the gluten of wheat, contain in addition to these, nitrogen and small amounts of sulphur and phosphorus. Hydrogen and oxygen are taken up through the roots of plants in the form of water, while carbon is taken from the air through the leaves in the form of carbonic acid gas. The atmosphere contains only about four-hundredths of 1 per cent of carbonic acid gas. There is, nevertheless, a great abundance in the air for crop-producing purposes.

Mechanical classification of soils.—Clay may be separated from the sand by stirring the soil with water, allowing the sand to settle, then taking it out, and evaporating the water from the clay which is left in suspension. The silt, sand and other coarser particles may be separated by apparatus devised for that purpose.

The following table shows how Professor F. H. King, in his book, "The Soil," classifies soils as to their mechanical make-up, showing the general proportions of sand, clay and decaying vegetable matter in the several classes of soil:

	Sand per cent	Clay per cent	Humus per cent
1. Sandy soil, containing...	80 to 90	8 to 10	1 to 3
2. Sandy loam, containing..	60 to 80	10 to 25	3 to 6
3. Loam, containing.......	25 to 60	60 to 25	3 to 8
4. Clayey loam, containing.	10 to 25	60 to 80	3 to 8
5. Clay soil, containing....	8 to 15	70 to 80	3 to 6

The so-called heavy soils are those made up too largely of clay, and are described as "heavy," because they are difficult to handle with the plow, cultivator or hoe. But the air space being greater, these soils, bulk for bulk, are lighter than the soils of coarser texture. They are soft when wet, tough when partially dry, and when dried they become very hard. Soils composed principally of fine clay will clog on the plow, the particles adhering very closely to the smoothest steel implement. Some of the densest clays are called gumbo soils. They are not only handled with difficulty, but they are too dense to allow an excess of water to drain out; they do not admit sufficient air; plant roots cannot readily penetrate them, and soil bacteria do not find in them favorable conditions for development. They stand more abuse under a poor system of farming than do soils of more open texture.

Light, sandy, gravelly or chalky soils are extreme in the opposite direction; being too porous, they dry out very readily. Most of these soils are not permanently productive unless treated very wisely. The air circulates in them readily, they are warm, their small amounts of organic substances rapidly decay and the waters of rains percolating down through them carry out a large proportion of the resulting soluble substances. They are sometimes called "hungry" soils. Barnyard or other vegetable manures decompose rapidly in these open soils and thus become quickly available for plants to use. These soils are also called warm, or quick, soils. They are ready for crops early in the spring, and, because the plant food is in an available condition, crops start quickly and usually grow rapidly in the first part of the season. They are also called drouthy soils, as they allow the larger portion of rain falling on them at once to percolate downward, retaining by their capillary forces only a small part. Their pores being so large, they do not readily bring up water from below by capillary action. On account of this porosity the air circulates in them freely in a dry time. Their total content of water is relatively small, and plants exhaust it rapidly. They dry out so rapidly that they often do not contain enough water for the roots of plants. In countries of ample rainfall, or where it is practicable to irrigate, and where barnyard manure or other complete fertilizers are easily procured, light soils often have an especially high value for raising vegetables, particularly early ones. But, as a rule, light lands are not very profitable for general farming, and the lighter they are the less profitable, especially in districts subject to periods of drouth. Many light soils are far better adapted to forest crops than to field crops.

Medium soils are made up of sand and clay, coarser and finer rock particles, mixed. They are sufficiently open to absorb large quantities of water, and they have the ability to retain it. They are usually productive soils, having large quantities of organic matter rather firmly "fixed," among the mineral soil particles. These soils provide the best home for the roots of plants, being neither too dense for the easy penetration of the roots, too close for the circulation of air, water and heat, nor too drouthy; and they provide a healthy place for those bacteria which are friends of the crop. These medium soils sometimes are given names indicating their geological origin, as till soils, bowlder clay soils, loose soils and alluvial soils.

On the prairies these soils are nearly black, and bear a rich covering of native grasses. In the timber sections they carry a heavy growth of trees, usually of the deciduous class. Color is not a very good general index to the richness of a soil; some rich soils are black, others red, yellow or other lighter shades.

These mixed soils are the golden mean: they form the kind of land upon which every farmer should be ambitious to establish himself and his family. Such soils often sell below their real value. They are the lands on which usually may be raised the best crops. These soils are most suitable for mixed and intensive systems of farming. They are adapted to grains, grasses, cultivated crops, roots, garden vegetables, small fruits and forest trees; in fact, to almost all staple crops for which the latitude is favorable.

Peaty soils, formed in wet places by the accumulation of vegetable matter in the water, where it decomposes only very slowly, differ from the three classes of soils named above in that they contain little mineral but much vegetable matter. When peat is well rotted, it is sometimes called muck, a soil term also applied to rich mud in the bottoms of streams or standing water.

In other cases, peat is built up on flat, level lands, where the constant supply of waters flowing down a long, nearly flat incline, or out of a seepy hillside, furnishes moisture to preserve the dead vegetable matter from decaying and supplies the needed conditions for the growth of peat-forming plants. These stretches of peaty lands, sometimes many miles across, are often covered with trees, such as tamarack and spruce; in other cases they bear only small shrubs, in some localities called heath, and in other places wild grasses and sedges grow. Dead trees, falling down, often become a part of the mass of peat in these low places, and mosses, such as sphagnum, form a large part of the peaty substance. Peat bogs, natural meadows, and muskegs are common names for wet areas of this class of soils, which, by open drains and subdrains, may be converted into arable soils suited to at least some of the crops grown on upland soils. Peaty soils are usually not nearly as valuable as good soils of mixed mineral particles. Some are especially suited to certain vegetables, as celery; in cold, temperate regions they grow better grasses, as red top and timothy for hay, than cereal or leguminous crops.

Alkaline soils occur where there is much evaporation from the soil, and very little rainfall and poor drainage. The alkaline character comes from compounds of soda and other alkaline compounds brought to the surface by the water, which rises by capillarity and evaporates, leaving the alkali either as a white or colored crust or in the soil near the surface. The plant roots find the water in the soil so strongly impregnated with certain of these alkaline salts that they do not make a healthy growth. Some soils contain such an excess of alkaline salts that they are nearly or quite worthless.

To show how these alkaline substances are deposited, one may take a glass tumbler, fill it half full of salt and then fill with water. If the tumbler is allowed to remain in a warm room for some weeks it will be observed that the water creeps up the sides of the tumbler and even over the edge and down the outside, and deposits a layer of salt on the wall of the glass. The water rises over the tumbler, by capillarity through this crust, and where it evaporates it leaves salt. In the same way many soluble salts in the soil are left at or near the surface, where the rising water evaporates. Thus in regions of light rainfall and very dry air, seepage water containing alkali, coming constantly to the surface in a low area, as at the foot of a hill, and there evaporating, often causes such an accumulation of alkali near the surface that most plants will not thrive. Some plants are accustomed to growing in soils containing considerable alkali.

Relation of air to soil and plants. Room for air in soils.—While most arable soils contain some relatively large particles, the bulk of these soils is composed mainly of very finely divided particles, $\frac{1}{25000}$ part of an inch and less in diameter. Soil materials divided into these very small particles have an immense total surface area. Many of the tiny surfaces are applied so closely together that they exclude air, and even water, from coming in contact with them. There are, however, in ordinary soils numerous interstices among the larger particles, which give room for both air and water. Soils containing humus will absorb and tenaciously retain more water than the same soils without humus. Soils hold in their pore spaces and on the surfaces of their particles, by the force called capillarity, considerable water. When this capillary force is only partly satisfied, these interstices serve as channels through which water can be moved from one part of the soil to another part from which evaporation or the action of roots has depleted the supply of water. The interstices are not filled with water, unless the soil is flooded or not properly drained. Soils rarely have even all their interspaces of a capillary size filled with water; in other words, the capillary power of soils is usually only partly satisfied. The larger interspaces are filled with air. Should the land be flooded with water, however, all these openings are filled, and the air, being lighter than water, is driven out.

The soil needs air to supply oxygen to the growing roots and to the germinating seeds; to assist in fermenting manures, dead roots and other fertilizing materials; to furnish oxygen for bacteria and other low organisms, part of which assist in preparing the soil for higher plants. Air needs to circulate in the soil to remove carbon dioxide and probably other deleterious gases, and to oxidize substances which may be unwholesome to plants. Roots of plants and germinating seeds will suffocate if not supplied with oxygen.

Earth worms, insects and small animals perforate the ground with holes and thus allow the air to circulate more freely; and they also help to mix the subsoil with the surface soil. Clover, alfalfa, corn and other plants with long roots which die and decay, leave air passages in the soil. After rains in summer, when the soil is moist and at a temperature suited to the growth of bacteria and fungi, cultivation lets the air in, presumably aiding many of these minute agencies in their work. When saline substances have been brought to the surface by capillary water, they are left there as a cement after the water has evaporated, and bind together the particles of surface soil into a crust. Here cultivation is necessary to open the soil to a freer circulation of the air. The soil is not such an inert mass as is generally believed. The particles are moved by the air, water, animals, plants, and by heat and cold, especially upon freezing and thawing. The soil is literally a slowly seething mass of inorganic and organic activities most vital and interesting.

Movement of air in the soil.—Changes in temperature of the air and soil and barometric air pressure cause more or less movement of air into and out of the soil. Air that is colder than the soil will displace the warmer air, thus causing the circulation of air into the soil; but air warmer than the soil will not so readily displace the colder air underground. The air upon flowing into the soil carries with it some gaseous products other than nitrogen and oxygen. Air serves as a medium through which the atmospheric gases can slowly diffuse into the soil, and through which free gases forming in the soil can escape into the atmosphere.

Movement of air in plants.—Plants as well as animals are said to breathe. Animals inhale oxygen and exhale carbon dioxide. Plants reversing the process, inhale dioxide and exhale oxygen. On the under surfaces of the leaves and in other places may be seen, by the aid of a microscope, certain small openings called stomata or breathing pores. These breathing pores communicate with the intercellular spaces of the leaves, forming channels through which the air circulates. In the interior of the leaves are found cells containing a green substance called chlorophyll. The air enters through these stomata, passes on in between the chlorophyll-bearing cells, and by osmosis gets into the cells containing chlorophyll. Here the carbon dioxide (CO_2) of the air is broken up through the action of sunlight into carbon and oxygen. The carbon combines with the water (H_2O) that has been taken up by the roots of the plant, and starch is formed. Thus 6 CO_2, acted upon by sunlight in the chlorophyll bodies, equals 6 C, and 12 O; and 5 H_2O (5 molecules of water) equals 10 H and 5 O; and when recombined equals $C_6H_{10}O_5$, starch, with 12 O to spare. The remaining 12 O, oxygen, liberated from the carbon dioxide, is given off, or is sometimes used for some purpose within the plant body.

This process of making starch can only take place when the plant is exposed to light. While it is not certain that starch is the first product formed in the plant, for the present we may consider it so. We may, therefore, look upon the chlorophyll bodies as little manufactories of starch. To decompose carbon dioxide and to build up starch out of carbon and water, requires energy. This the plant obtains from the sunlight. When the animal consumes the plant, it breaks down these compounds and changes part of the carbon back into carbon dioxide and water. The stored-up energy is liberated, and is used by the animal for the production of work or heat or for other bodily functions requiring energy.

Animals depend on plants.—Animals cannot combine the nourishment in the air and soil for use as food. Plants, however, take the food substances available in the air and soil, and by the aid of sunlight build these into compounds useful to animals and man. While only a very small part of the food of plants is obtained from the soil, their growth under ordinary conditions depends directly upon the soil. It is necessary to understand the needs of the plant and the character of the soil so that the land may be handled in the manner best suited to the needs of the crop we wish to grow. The soil is a medium through which the plant obtains water containing in solution the mineral and other parts of its food, excepting the CO_2 secured from the air. That the soil is only a medium, is shown by the fact that plants can be grown in pure water, to which is added the necessary nitrogen, phosphoric acid, potash, iron, calcium, etc., required by the plant when grown normally.

Drainage and cultivation accelerate soil aeration.—Drainage, especially tile drainage, where the drains are put in near together in heavy, close soils, accelerates the circulation of air in the soil to a considerable degree. Drains remove the water, allowing the air more room among the particles at a greater depth. When rain causes the surface of the free water, or ground water, in the soil to rise, the air is, of course, crowded out of this saturated part, but when the surface of the zone saturated with water, is again lowered by the drains, the air again settles into the interstices among the soil particles. Drainage allows the roots of plants to penetrate deeper, and these, on decaying, leave deeper holes through which the air circulates more freely in dense soils. It also increases organic matter, bacterial action and plant feeding deeper down in the subsoil.

Plowing and subsoiling give aid to all these forces which tend to make air circulate in the soil. In very dry weather, clay soils sometimes become so much shrunken that large cracks are produced and through these the air can circulate in the soil. In the northern states freezing does a great deal to prevent the soil from becoming too compact. By the freezing and the resultant expanding of the soil, the particles are pushed apart and left more open for the following summer season. Vegetable manures make dense soils looser, and open soils closer; in both cases adding to the power of the soil to retain water and soluble plant food.

Soil water and the plant.—The plant secures its mineral and nitrogenous food supply through the water in the soil, absorbing it through the membranous surface of the new roots and root hairs. These root hairs, which are elongations of the outer cells of the new root near the growing point, increase the root surface, extend thin membranous branches out into contact with the soil and enable them to absorb more of the soil moisture and secure more food. Only a small part of the water taken up by the plant is used in forming new tissue, but passes to the leaves from which it is transpired into the air. The plant food from the soil is usually in very dilute solutions. All the cells are kept charged full of water, which holds the soft parts of the plant rigid and upright. The water is given off through the same openings in the leaves which take in the carbonic acid gas, and on warm days the evaporation of this transpired moisture helps to keep the leaves cool. Since the quantity of water transpired through the leaves amounts to from 200 to 800 pounds for each pound of dry matter produced by the plant, a good crop of grain or of forage will exhale from its leaves during the season several inches of rainfall; that is, sufficient water to cover the soil to the depth of several inches.

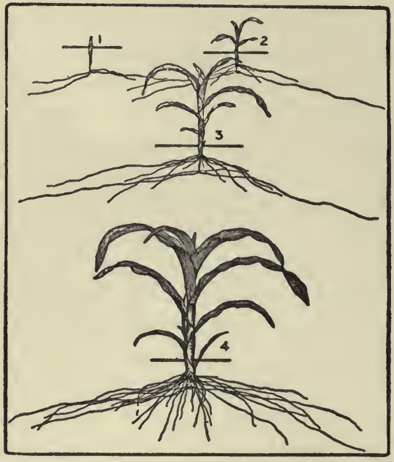


Figure 17. Corn accurately drawn from measurements made in 1886 representing corn (1) at ten, (2) twenty, (3) thirty and (4) forty days after planting. The drawing represents a width of 4 feet 6 inches. The whorl of roots which spring from the seed or seminal whorl, as at 1, and the whorls which arise from the bases of the sheaths of the first, second and even the third and fourth leaves or blades, strike out through the soil in the early, cool, moist spring season in a nearly horizontal direction. Those springing from the fourth, fifth, sixth and later nodes or joints go nearly downward, so as to hunt better for water in the drier, warmer midsummer. The early and especially the later roots springing from the stem—stem roots—send out many branches with sub-branches reaching every part of the soil. The roots of corn planted in hills 4 feet apart each way, even in the young stage, as at 4, have no trouble in reaching all parts of the soil between the rows, often overlapping 1 or 2 feet with the roots of the adjacent rows.

Extent of roots of crops.—The roots of our field crops are much longer, much more numerous, spread farther, and penetrate into the soil to greater depths than is generally realized. On fairly open, easily penetrable soils, where the upper portion of the earth is too dry for the plant to obtain sufficient food, roots are sent downward four to six feet, and in some cases much deeper. In humid regions, however, the greater number of fine root branches are found in the first foot or 18 inches of soil, in which are the best conditions for the roots to secure food. The depth at which most plants prefer to feed, if sufficient water is present, is the lower half or two-thirds of the furrow-slice, and that part of the subsoil immediately beneath. While the roots which go deepest into the earth secure some food, the chief function of the deeper roots is to bring up water when the supply near the surface is deficient. These long, deeply penetrating roots have few branches near the tip, while nearer the surface of the soil the root branches are very numerous. The roots spread out so as to reach the plant food in every nook and corner of the furrow-slice and uppermost layers of the subsoil.

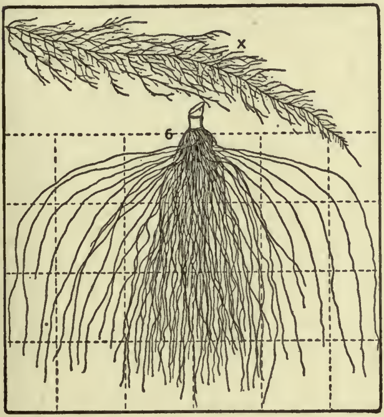


Figure 18. At 6 are shown the stem roots of a corn plant nearly ready to tassel out. All these roots have their origin in the base of the stem, and each one has many branches, as shown at X. The dotted lines mark off square feet. The largest roots penetrate nearly 4 feet downward, while the horizontal spread, including the branches, not shown in 6, is over 6 feet. This drawing was made from a plant, nearly every stem root of which was dug out by means of a small wooden trowel, the length, depth and direction of the root being accurately recorded on the drawing.

In Figure 18 is shown the root system of a corn plant ready to tassel. The branch roots are not represented at 6. They are so numerous that it is impossible to show all of them in this diagram. The roots there shown are the mere framework, or main roots, their branches and sub-branches being very much more numerous. At "X" is shown one of the roots arising from the stem, with its branches. Only the outer, recently developed ends of the main root are active in absorbing water containing soluble plant food. The older surfaces of the roots are covered with a tough layer of barklike cells and these portions of the roots serve only to transport water carrying soluble plant food up to the stem, and to hold the plant in place. In Figure 17 are diagrams showing the roots arising from the stem, but not the branch roots, of corn at about 10, 20, 30 and 40 days, respectively, after planting.

Figure 19 shows the general spread of the roots of a wheat plant. The roots of other cereal grains are quite similar to those of wheat. The roots of our tame grasses also penetrate to similar depths. Clover roots go a little deeper than the roots of the grasses and grains, while the roots of some perennial field crops, like alfalfa, under unusually dry conditions, may go to a depth of more than 20 feet. But in all cases the plants, whether small, or even if as large as trees, procure most of their food in the furrow-slice and upper layers of subsoil. Since the furrow-slice and the part of the subsoil just below it are the portions of the soil which supply to the roots of crops the most congenial and richest feeding zone, the aim of the farmer should be to

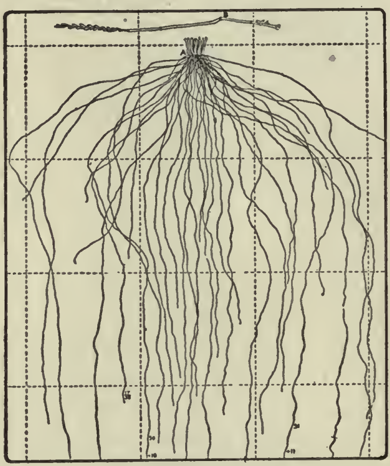


Figure 19. Crown and stem roots of a mature wheat plant, from one seed. This plant stood alone and developed over a dozen culms. There are about 100 stem roots, which alone are here shown, each of which had for some distance on an average about eight branch roots to the inch, making a wonderful mat of roots in the soil. Numerous roots penetrated to the depth of 4 feet and the spread of the roots had a diameter of more than 3 feet.

keep these zones of soil supplied with the proper amount of moisture and vegetable matter and to provide for the mechanical conditions which best promote the growth and yield of crops. Where there is a lack of mineral plant food this also must be supplied.

Film water and free water.—In order that the relation of water to the roots of plants may be better understood, the following explanation is here presented: Place a pot of soil in a hot oven and leave it until nearly all the moisture has been dried out. If the oven is kept at the boiling point of water a day or longer, practically all the soil moisture will have been changed into steam and driven off into the air as vapor, and the soil will weigh much less than before. Even at the boiling point of water the soil will so tenaciously hold to the last particles of water that a very small amount will remain. We will assume that we have one hundred pounds of water-free soil in the pot. (Figure 20.) Now place this pot of dried soil in a room between open windows where the air can freely pass over it, but where no rain can strike it. Upon weighing the pot of soil some days later we find that it weighs a few pounds more than when it was removed from the oven. (Figure 21.) This increase in weight is due to moisture which the soil has absorbed from the air, just as ordinary salt will absorb moisture from the air. The air always contains water in the form of gas, often called vapor. If we now close the room up tightly and place several large kettles of water on a stove and cause them to boil vigorously, the water will "boil away" and the vapor will become an invisible part of the air of the

Figure 20. Pot of 100 pounds of soil from which all water has been forced out by baking.

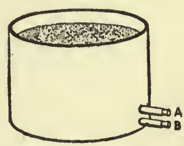


Figure 21. Pot of baked soil after standing several days in the air, when it weighs a few pounds more from the absorption of "hygroscopic" moisture.

room. The soil in the pot will again increase in weight, since it will be able to gather more water from this very moist air than it had secured from the relatively dry air which came through the windows. We will assume that the one hundred pounds of fire-dried soil, when exposed for some days to the outside air, absorbed three pounds of water, and that when it was put in the air made very moist by the boiling water, it absorbed two pounds more. This moisture is held in the soil as a delicate film about each soil particle, or within the minutest pores in the particles of soil, but is not sufficient to bind the particles together as does the larger amounts of capillary moisture mentioned below. The finest, driest road dust contains from one to ten per cent of moisture in this form.

By means of a fountain throwing a very fine spray on the surface of the soil in the pot, a miniature rainstorm may now be produced in the room. As the tiny raindrops strike the surface of the air-dry soil, they are eagerly seized by the surfaces of the small particles of soil. While the soil could not gather and condense any more of the vapor from the air and associate it with its own particles, the surfaces of soil particles at once show a strong attraction for this finely sprayed water, or vapor condensed to the liquid form. The water and the surfaces of the soil particles seem to desire the closest touch with each other, and, as the water is a mobile fluid, it spreads out in thin layers over the attracting surfaces of the minute soil particles, enters into the pores within the particles, and fills the capillary spaces among them. If one particle has a thicker layer of water on its surface than its neighbor, the water is soon equalized over all. If in traveling from particle to particle the film of water finds a pore space or interstice unoccupied, it flows into that. As the rain proceeds the particles at the top of the soil become surcharged with water. The water-attracting power of the surfaces of the uppermost soil particles is satisfied, and they allow the layer of particles next beneath to draw away the surplus. In this way a very gentle rain is taken hold of by the soil particles, and is slowly moved or drawn downward by what is termed the capillary force of the soil. The soil thus takes the moisture downward in much the same manner as a sponge, when placed with its lower portion in a small amount of water in a saucer, absorbs the water upward into its own body, though very much more slowly. Gravitation, of course, aids the downward capillary movement, and slightly retards its upward movement, as in the sponge. When filled, or saturated, to its full capacity with capillary water, the 100 pounds of original dried, water-free soil, with its added water, weighs, perhaps, 145 pounds. In Figure 22 the soil is shown to have its capillary powers saturated in the upper half.

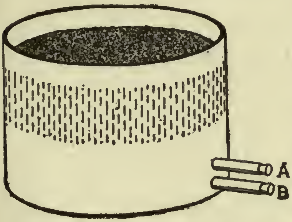


Figure 22. Pot of air-dry soil after a very fine rain has been falling on it for some time. The capillary power of the soil has been satisfied nearly half way down through the mass.

Crops could not thrive in soil as dry as that represented in Figure 20 or even that in Figure 21, with only hygroscopic water present, but plants which thrive in our arable lands have, through the centuries of their development, become accustomed to soils with their capillary forces only partly satisfied. Soil with its capillary forces fully satisfied with 45 pounds of water to the hundred pounds of soil, would be so wet that corn, and most other crops, would not

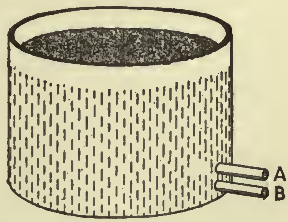


Figure 23. Capillary powers of the soil satisfied to the bottom of the pot.

thrive so well as if it contained only 20 to 35 pounds of water to the hundred pounds. If the rainfall continues until no more soil with unsatisfied capillary power exists below, the excess of water percolates to the bottom of the pot, obeying the law of gravitation, and there fills the larger interstices, crowding out the air. This water is called ground water. As the rain continues until the ground water has filled all the openings in the soil, the surface of this ground water gradually rises among the soil particles in the bottom of the pot, forcing the air out from among the soil particles. Thus in Figure 24 the ground water is shown to have filled the lower half of the pot, while in the upper part the surfaces of the particles are covered with what water the capillary spaces and surfaces can hold. This excess of rain, upon entering the soil, no longer retarded because all capillary force is satisfied, simply obeys gravitation, percolates vertically downward until it reaches the surface of the ground water. In most of our more open soils this excess water sinks far downward until an impervious layer is reached, where it forms the ground water shown by the level of water in the wells. With the continuance of the rainfall, if the spouts A and B in the pot be closed, the ground water will rise, completely filling the interspaces within the soil. More rain will cause the water to stand above the soil as *surface water,* and to run over the rim of the pot, as in Figure 25. If the spout A, Figure 26, be now opened, the surface water and the ground water will gradually drain out to

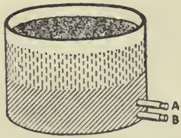


Figure 24. Pot of soil after rain has fallen on it until the capillary powers of all surfaces are satisfied, and the rainfall continuing, ground water has filled the interstices or pore spaces between the particles of soil, displacing all the air in the lower half of the mass.

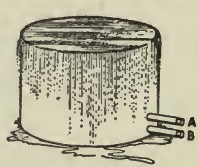


Figure 25. Pot of soil after rain has fallen on it until the soil pores are full of water; the rain continuing, surface water has accumulated, filling the open space in the top of the pot and running off over the rim.

the level of the spout. The soil will still be very moist, but, if placed in the dry air of a living room, the drying action of the air will soon remove some of this excess by evaporating moisture from the surface particles. These, in turn, will be given some of the capillary moisture from the particles next below. Thus there will be a slow, upward flow of moisture, similar to the upward movement of oil in a lamp wick, or to the upward movement of water into which the lower part of a sponge is inserted. If the ground water is sufficiently near the surface, it will be a source of moisture, keeping the soil and subsoil partially saturated with capillary water, thus providing the crops with a constant supply of water. In Figure 26 the water in the bottom of the pot not drained out, because the drain at B remains closed, will be a permanent source of capillary water to the upper soil, to renew that taken up by evaporation from the surface of the soil into the air above, or that absorbed by plant roots growing throughout the upper portion of the soil. The air within the soil is kept very moist by the evaporation which takes place from the many moist surfaces. This watery vapor in the soil air diffuses outwardly into the atmosphere above, aided somewhat by the slight circulation of air into and out of the soil, thus causing some loss of moisture which does not pass off through the plant. These losses will gradually use up all the ground water held below the upper drain, Figure 26, and leave the soil with only capillary water, as in Figure 27. The soil filled only with capillary water, as in Figure 27, is also gradually dried

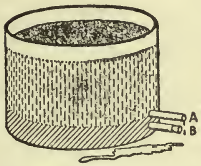


Figure 26. Pot of soil after drain, A, has been opened and all of the ground water but that part below A has drained out.

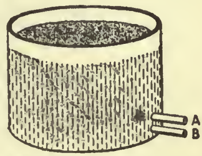


Figure 27. Pot of saturated soil after the water below A has been drawn upward to supply that gradually evaporated from the surface, leaving only capillary water in the soil.

out by the air, if left in a dry room, so that only hygroscopic moisture remains. If the pot is again placed in an oven which is kept at or above the boiling point of water, the soil will be again reduced to the water-free state, as in Figure 28.

Figure 29 illustrates the fact that the capillary force carries water in all directions in the soil. A funnel tube is used to carry water slowly to the center of the mass of earth made air-dry, as in Figure 28. The particles immediately surrounding the point of the tube are saturated with the water. This water clings to the surfaces of the particles and spreads out in thin films over surrounding particles. The attraction of the neighboring soil particles causes these films to stream outward toward drier particles where the capillary forces are less satisfied. Thus the moisture moves upward and sidewise nearly as rapidly as downward, in which direction gravitation helps to move it, while slightly retarding the flow over surfaces in other directions, especially its upward movement.

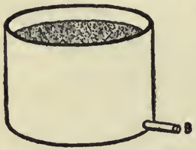


Figure 28. Pot of soil from which the capillary moisture has been dried out by exposing it for some weeks to the air, followed by several days of baking in an oven sufficiently hot to turn all moisture to steam, and thus driving it out leave the soil dry of water, water free, "dry substance," as when pot 1, Figure 20, of baked soil was first placed in the air.

The soil acts like a sponge.—In regions of light rainfall most soils, instead of having this underground supply of water stored up to be given out gradually, are generally not very moist at a depth of several feet. The rain which falls upon the soil, in part runs off over the surface, especially if it be hard or if the land be hilly. That which is drawn in by the capillary force or sinks in by gravitation, is taken up and held as capillary water, or is added to the ground water. A light rain is carried downward a short distance only, while a heavier rain will go correspondingly deeper. Continuous rainfall for a number of hours is necessary, to penetrate to the depth of several feet and to satisfy entirely the capillary force of a dry soil.

In case sufficient rain falls to penetrate to only a few inches, the moist surface soil soon begins to give up its moisture in two directions. The moister particles give up their water to the drier soil particles beneath, as was described above, and as soon as the sun warms and dries the air at the surface, moisture is there evaporated, and there is a consequent movement of water within the moist upper zone or layer of soil toward the sun-dried surface particles. These movements will both continue for a time, but soon the zone of moist soil, will have given up sufficient water so that it is no moister than the subsoil below, and the downward movement will cease. But since the sun and wind are in almost daily action in summer in evaporating water from the surface of the soil, there is a movement of capillary moisture upward nearly all the time. Part of this moving mass of water is intercepted, in its slow upward flow, by plants, which take it into their roots, pass it to the leaves and there transpire it into the atmosphere.

Figure 29. Pot of air-dry soil, containing only hygroscopic water. Through the funnel tube water is slowly run into the center of the mass of soil. The water is carried away from the point of the tube in all directions by the force of capillarity. Gravity causes a slight tendency for more to go downward than in other directions. But capillarity, being much the more powerful acting force under these conditions, causes the water to go upward and sidewise as well as downward.

Water-holding power varies with different soils.— Some soils retain much more hygroscopic moisture when air-dried than others, some soils will hold a much larger amount of capillary moisture than others, and soils vary greatly in the amount of water which can flow into their interstices as ground water. Thus a hundred pounds of soil containing clay or vegetable matter, when drenched with water, will cling to, and prevent from running out of, its body much more water than will a sandy soil. In soils which are so constituted as to hold much water, plants can better endure either periods of drouth or an excessive rainfall. Vegetable manures added to soils, green crops plowed under, or the roots of plants in the soil, soon decay, and while decaying these substances aid the soil in retaining capillary moisture.

Capillarity illustrated.—The word capillarity has such an important use and meaning that an explanation is necessary. It is derived from the Latin word *capillus*, meaning a hair.

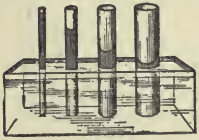


Figure 30. Showing how water rises in small capillary tubes. It rises higher in the smaller tubes than in the larger ones.

In Figure 30 are shown several very small glass tubes with their ends dipped in water. It will be observed that the water rises inside the tubes. The water and the inside surface of the glass have an affinity for each other sufficient to draw the fluid up into the tubes. The fact that this action of water in very minute hairlike tubes was the first clearly observed case in which water attached to and crept over surfaces and through small openings is probably the reason that the name capillary action was given to this movement of water in the soil. It will be observed in the illustration that the water rises higher in the smaller tubes than in the larger ones. The force exerted is the attraction of the water and the inner surface of the glass for each other. In the small tubes the surface of glass is larger in proportion to the load of water than in the tubes where the column of water has a greater diameter. The action of this force is further illustrated in Figure 31, showing that it is not the form of the tube, but the attraction of the surfaces of the glass, which carries the water upward. The attraction of the water for the surfaces is

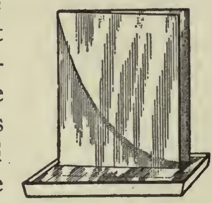


Figure 31. When two plates of glass, placed so as to touch at one edge and ⅛ inch apart at the other edge, have their ends placed in water the liquid rises up between them as shown in this figure, the water rising highest on the side where the two plates are closest together.

called adhesion. The particles of fine clay being several hundred times smaller than the particles of coarse sand, there is presented to the water a very much larger total area of surfaces in a given bulk of clay soil than in sand; and, therefore, the total area of the surface films is much greater. In case of a soil filled with ground water, as in Figure 26, where the drain is opened, the movement is downward in response to gravitation. When all this hydrostatic or ground water has been drained out, leaving the soil with its capillary power all satisfied, the films covering the particles are relatively thick. As the soil dries out from evaporation and through removal by the roots of plants, this film becomes thinner, until only the hygroscopic water—that which the air cannot take away—remains. When the films are thick, the capillary water moves rather freely toward a point where a root is exhausting the supply; while, where the film is thin, there are many more openings, or spaces, in the soil, and the movement of water is much retarded by the friction in the thin films. The movement of water and plant food toward the growing roots of plants, however, is not so rapid as many suppose.

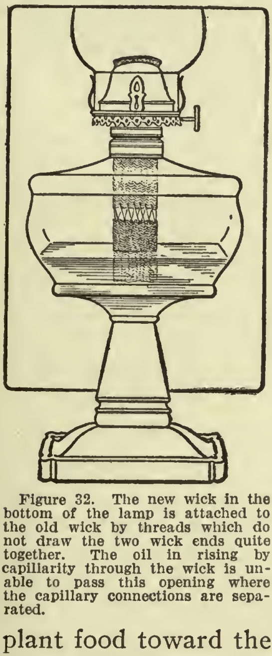


Figure 32. The new wick in the bottom of the lamp is attached to the old wick by threads which do not draw the two wick ends quite together. The oil in rising by capillarity through the wick is unable to pass this opening where the capillary connections are separated.

Other facts concerning this interesting force are shown in Figures 32 and 33. A new lamp wick, Figure 32, is attached to an old one, which has become too short to reach the oil, but the threads connecting the two ends are not drawn tightly, leaving the two ends slightly apart, and the interstices among the threads between the two wicks being too large to form capillary spaces, little or no oil rises to the flame. In Figure 33, at a depth of several feet, A, there is ground water; at B, the soil is well supplied with capillary water; at C, as is often the case in very dry sections of the country, a layer of coarse straw, lying up dry and loose, is plowed under. The moisture cannot pass by capillary movement upward through the layer C, to moisten the furrow-slice, D, and the "moisture line," or the zone of capillary moisture, rises only to C; thus shutting off the seeds from obtaining water from D, just as the oil fails to rise to the flame in the lamp in Figure 32. The layer of coarse straw makes a mulch of the entire furrow-slice, protecting the moisture below from rising and wasting by evaporation, which causes injury by forcing the roots of the plants to feed only in the subsoil. In most countries there is sufficient moisture so that a layer of dry straw soon decays and no longer acts as a barrier between the subsoil and the furrow-slice. The stronger capillary power of the decaying plant substance, on the other hand, secures and holds within itself larger amounts of water, and thus both water and plant food are most liberally supplied to the

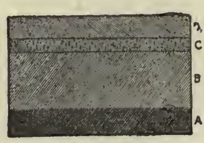


Figure 33. Soil saturated with standing water at the bottom, A; supplied with capillary water in the upper subsoil, B, by the water rising from the supply of ground water. At C, a layer of coarse straw is represented as having been plowed under the furrow-slice, D.

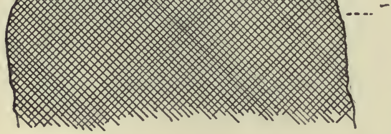


Figure 34. E, subsoil. D, furrow-slice with dust blanket at surface shown darker. Upper surface of capillary water here rises through the lower half or two-thirds of the furrow-slice, F, to the bottom of the dust blanket, C.

roots and the plant feeds in the upper soil zone which contains the most plant food. Where the recently plowed furrow-slice is very porous and loose, it also acts as a mulch to retard the upward flow of moisture by capillarity.

Dust blanket and dirt mulch.—The use of a dirt mulch or dust blanket is illustrated in Figure 34. Here the furrow-slice, D, rests upon the subsoil, E, with which it is in intimate contact, so that the capillary water may rise into it. To prevent the water from rising entirely to the surface, there by the aid of the sun's heat to be evaporated into the atmosphere, the upper zone of soil, C, is kept broken up and made too mellow and open for the water to rise through it by the force of capillarity. The moisture line here is at the bottom of C, thus bringing the moisture zone up so as to include the lower two-thirds, F, of the furrow-slice D, and allow the roots of crops to feed in this portion of soil, which is not only the richest in plant food, but is the most congenial for the roots of plants and for their little helpers, the soil bacteria.

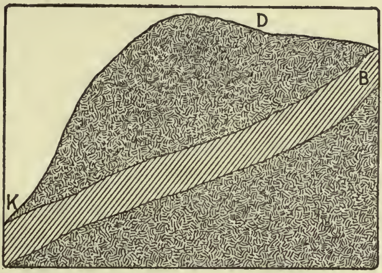


Figure 35. Shows a pervious mass over a layer of impervious clay or stone, B. Water falling on tho upland at D, sinks down to the impervious layer of clay and seeps forward until the hillside is reached, and there flows out, resulting in a seepy hillside, as at K, or possibly forming a definite spring.

The general movements of water in the earth.—The surface of the water in our wells shows that the ground water does not actually rise near the surface. The upper part of the earth acts as a storage sponge, and gets its supply of water annually from the rainfall, excepting cases where irrigation is practiced, or in rare cases where water seeps out of hillsides and forms moist, springlike areas, or flows along porous layers underneath level tracts, there serving as natural sub-irrigating waters to be drawn upward by capillarity, or to be reached direct by the roots of plants. Porous earth, as at D, Figure 35, allows part of the rainfall to sink deeply. This upon reaching a porous layer, as gravel, B, lying upon impervious clay or rock, seeps sidewise, reaching the surface at a lower level, K. Here it may flow out as a spring, or simply seep slowly out, and result in keeping the hillside moist, or it may flow down through the open soil in the valley and keep that moist, or it may flow into an open water-bearing stratum with impervious clay or rock both above and below, and lie there with very little movement. In such cases this water is often subjected to great pressure, because the head of water above, as at B, Figure 36, is high. A well sunk into such a vein of water under pressure, makes an opening through which artesian water rises to, or above, the surface of the earth, or oftener only a short distance in the well.

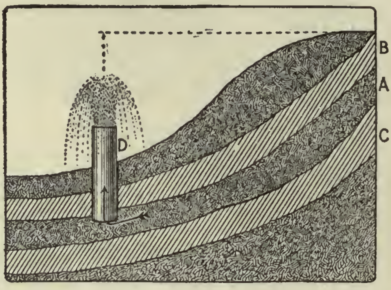


Figure 36. Shows how water confined between impervious strata, as in A between B and C, is subjected to pressure, making it possible to secure flowing wells, as at D. The water of rains, sinking in the pervious earth to the right of A, flows between the impervious layers. The pressure at any point is sufficient to force the water to rise to a height somewhat less than the height of the water in the region where it enters the soil.

In regions where the rainfall is not ample, the furrow-slice should be kept as mellow as practicable so as to give easy access to rain water, that none may be lost by flowing off over the surface. An open, loose furrow-slice, four or more inches thick, in a climate with too little rainfall and with dry, hot atmosphere and drying winds, does much to retard the loss of moisture from the soil by evaporation. The moisture line, under such conditions, rises only to the bottom of the furrow-slice and the roots of crops must feed in the subsoil, not being able to get food from the dry, porous furrow-slice. For this reason spring plowing for spring-sown grains in dry regions sometimes serves as a more open, more efficient dust blanket than the more compact fall-plowed furrow-slice, and thus sometimes enables the farmer to produce better crops than autumn plowing, which is ordinarily the better practice in humid regions. The stubble standing on the land over winter in a windy country often holds snow which, upon melting, largely enters the soil, leaving it more moist in the spring than would be the wind-swept fall-plowed land. The looser spring-plowed furrow-slice, then, better conserves water from melting snows and from spring rains.

On the other hand, the loose furrow-slice affords very poor conditions for seeds to germinate, and, under most conditions, the better results come from having the lower part of the furrow-slice compact and the upper part kept open by cultivation to serve as the blanket of loose earth, or dirt mulch, to retard evaporation. Under very dry conditions the deep, loose furrow-slice is so open and dry that seeds will not germinate; and a heavy rain is required to make the furrow-slice sufficiently moist to provide the necessary moisture to start the seeds. A still heavier rain is required in order that moisture may penetrate to the solid earth below the furrow-slice, there to become a part of the stored-up water of the subsoil.

The moldboard or disk plow inverts and pulverizes the soil, and mixes into it such stubble and weeds as may have grown, and such manure or other fertilizers as may have been applied to it. The weight of the earth, the action of water, bacteria and other agencies which encourage decay, bring the coarse vegetable matter and the lower part of the furrow-slice into a compact mass closely adhering to the subsoil. The cultivating implement again loosens the upper part of the furrow-slice in the preparation for planting, and keeps it loose and open during the cultivation of crops planted in rows for intertillage. Both plowing and tillage have other functions than so controlling the water as to provide the optimum amount of film water best for the plants. Crops thrive with an amount of water somewhat less than that required to entirely satisfy the force of capillarity, and can adjust themselves to some range of moisture content between saturation of capillarity and such a low amount of water that they cannot get all they need, and wither, and are stunted in their growth. In drouthy regions, the application of water and the conservation of soil water are often the controlling factors in crop production.

CHAPTER VI

THE SELECTION OF A FARM HOME

The selection of a farm for a permanent family home is a matter of great importance. Here most of the life is to be spent; and upon the quality, character and location of the farm largely depends the success and the happiness of each and every member of the family. Its importance as a place for developing the home, bringing up a family, enjoying family ties, entertaining friends, and working out life's success, can hardly be overestimated. If its location is unsuitable, its soil poor or difficult to subdue, or if it be otherwise poorly adapted to the particular needs of the family, there may be lifelong regret at the choice. It is highly important to the farm family to feel that it is permanently located, and that whatever is done to build up the place is done with a view to its permanent usefulness as the foundation of a happy and prosperous home, for generations, of a strong, prosperous family.

The farm the foundation of the business.—Each farmer should choose a farm suited to the kind of farming he desires to follow. It is far better to spend some time looking about, so as to be fully suited, than to take a farm that is easily obtainable, but not just adapted to the kind of farming to be done. A fruit farm too far away from market, a sheep farm on too low land, or a grain farm in a sandy, wooded country, would be an unfortunate choice. In such regions as the great prairies of the upper Mississippi valley, one can easily find lands suited to general farming, that is, to the production of grain, forage crops and live stock in combination. But if one wishes to do vegetable gardening, he should avoid the heavy lands and secure a soil somewhat lighter. On the other hand, it is often necessary to adapt the business to the farm which it is practicable to secure.

Producing capacity.—Generally the producing capacity of the soil is of the greatest importance. The lands of the western states are rising in value and in price from decade to decade. Lands with large native fertility will generally rise in value more rapidly than will the more sandy lands, or lands which for other reasons are not especially productive. No one ever hears of farms on mixed black prairie soils of the west being abandoned, as are sometimes the farms of hilly New England, or the sandier lands of the pine regions, or the drouthy lands of the Great Plains area. The soil surveys of the United States Department of Agriculture and of some state bureaus will be great aids in selecting the regions to investigate for good soils and desirable farms.

Ability to withstand drouth.—Drouth resistance is another important quality, especially to soils in, or bordering on, the great semi-arid regions. Here it is not so much a question of fertility, as of soil moisture. Farming on drouthy, sandy or gravelly soil is more speculative; one year the crop may be satisfactory, but another year the crop is ruined by the drouth. Generally, sandy lands sell for more than they are worth, while the reverse is true of the stronger lands. Far to the north, heavy lands are at a disadvantage because they are too cold.

Healthfulness.—In choosing a locality in which to purchase a farm, a healthful climate is of importance, as such a climate is necessary to develop strong, useful and happy people. Many sections once unhealthful, as large parts of Indiana and Illinois, have been made healthful by drainage, and many regions needing drainage will, ere long, be so completely drained as to be free from malarial diseases. Sufficient and evenly distributed rainfall is of prime importance. Irrigation can be resorted to in some districts, and, where there is an abundance of water, farming under this plan is even more satisfactory than where the dependence is upon rain. In irrigation the water can be supplied when needed, and there is usually no rain to interfere when crops are being cured. Often farms needing drainage or irrigation can be purchased, and drained or irrigated with great profit by those who know how to make these improvements.

Proximity to markets and large cities is a very great advantage. One cannot forecast how the farming business may develop, and, in any event, nearness to competitive markets is of great importance to the farmer. Large cities provide many advantages which cannot be enjoyed by those who live far from the great centers of population. Higher prices can be paid for lands near large cities. Not only is the cost of freight less on the products to be sold or purchased, but advantages may be taken of city opportunities of many kinds, if the trip by steam, or trolley, or team be not too long. It is also a great advantage to farmers to come frequently into contact with the bustling life of cities.

Character of neighbors.—It pays the home seeker to consider carefully the class of neighbors surrounding the farm he contemplates selecting. People generally do as those about them show that they expect them to do. The farmer and his children are more likely to be altruistic, lovable, honorable, industrious, businesslike, enterprising and thoroughly up to date if they live among neighbors who are congenial, upright, industrious, thrifty and up with the times. Life is not all the "raising of corn, to raise more hogs, to buy more land, to raise more corn," etc.; the enjoyment of social and public life, as well as the enjoyment of home and family, are considerations of the very highest importance. It is very desirable that the neighbors with whom one must associate, exchange views and confidences, and with whom the children of the family must associate in school, in church, and in social functions, should be somewhat similar in tastes and habits and withal honorable and agreeable. Many a farmer has become backward and even morose because of a lack of social life.

Children in rural homes learn how to do with things better than they learn how to think about things. They need to go to school and be taught to think about things around them, but, quite as important, they need to learn how to think about people and to do with people. Rural youths can nearly as well afford to fail to learn books as to be deprived of contact with their playfellows at school and with the people they meet at church or at other gatherings, as in the farm home or in the village. Proximity to good schools and churches, and nearness to town centers, are all of large value in making up a decision as to where to select a farm.

Care in judging the value of soils.—In inspecting the soil itself, it is easy to determine whether a soil is clayey, sandy, gravelly; or, if a mixed soil, whether it is the happy medium, or golden mean, made up of nearly equal parts of sand and clay. The texture of the surface soil when wet, and also when dry, should be observed. The heaviness or ease of tillage operations should be taken into consideration. Other factors to be taken into account are whether the land is level or hilly, whether there are many stones to be removed; and often the number, size and kind of stumps, must be considered.

The butter dealer will inspect every jar of butter with his butter trier, or, at least, a sample of every lot, but the farmer too often looks only at the surface soil. With the aid of a common spade or with a post-hole digger, the subsoil to the depth of three or more feet may easily be observed; and since one can in this way make the best analysis of the soil and subsoil, it should never be neglected. In many cases upturned stumps show the quality of the subsoil, and burrowing animals may have brought to the surface the deeper earth. The experienced land judge has many ways in which to determine the quality of the soil. The person who will make an earnest effort can find many ways of judging the fertility, the water-holding power, and the wearing ability of a soil. Growing crops tell their story, though the kind of season must be taken into consideration. Sandy lands may have large crops during a moist year, partly because drouth for a few previous seasons may have so prevented the growth of crops that there are unusually favorable conditions for plant growth, resulting in an exceptionally large crop. The testimony of residents on adjoining lands is of the greatest value, especially if the home seeker knows how to draw out and weigh information.

One need not depend upon the appearance of the cultivated grasses and clovers alone, but can find out much about the soil by the native plants. Land which produces a thick crop of large weeds, either native or introduced, gives evidence of strength and crop-producing power. In timber sections trees are much used as an index to the character of the soil. Thus, in the North, jack pine grows on very sandy land, Norway pine on land usually not quite so sandy, white pine on still stronger sandy loam and on mixed soils.

Some kinds of oak, in a given region, will be found to grow on sandy land, other kinds only on strong soil of mixed sand and clay. Sugar maples and some other deciduous trees grow only on the strong mixed soils. Where soil surveys have been made by the Bureau of Soils of the United States Department of Agriculture, or by a state department or experiment station, the soil maps showing the areas of soils of different classes will be found valuable aids in selecting a farm.

Special and general considerations are often worthy of attention. A perennial spring of water near the barns or near the dwelling has value. The ease or difficulty of getting well water should be noted, also the quality of the water. The possibility of using irrigation water often modifies the desirability of the land. Not only in the Plains Region, but even east of the Mississippi river, waters for irrigation will no doubt sometime be highly valued. In a new section of country, free pasturage of commons which are likely to remain open to the public for a long series of years, may have considerable value in connection with the farm to be bought.

The purchase and building up of a farm is such a serious life matter that the farmer should look the entire situation over beforehand with a view to locating buildings, developing the fields, etc. It is very desirable to have land suitable for evolving a highly organized farm. A place is needed for buildings where there is good drainage, opportunity to protect from cold winds by means of a grove, land for garden, orchard, lawn and stock paddocks. This location should be so situated as to be readily accessible, by means of lanes and cartways, to all the fields of the farm. The cost and ease of development, including the cost of clearing, breaking, draining, laying out fences and developing the fields of the farm, are all matters which should be carefully considered at the time the choice is being made among the different farms under consideration.

Hunt for a bargain.—It pays to hunt for a bargain. Occasionally farms are offered much below their normal or intrinsic values, but the effort to make a profit on the purchase price should not be carried so far as to settle on land which is not suitable for the kind of farming to be entered upon, or is otherwise very unsatisfactory as a permanent home for the family. No other part of the farmer's remuneration has the high value of the happy home life. We may not look too much at money getting, but we certainly do not look enough at home making. The farm home is a little world in itself. Its sunshine, its joy, its influence in producing strong happy people, its potentiality of national strength, its power in conserving morals, its opportunities for man's communion with nature and nature's God, combine to make it important. We should choose the farm home wisely, that we may there express our lives in doing what we can for ourselves, our families and our country.

CHAPTER VII

PLANNING THE FARM

General foundation plans for the farm are next in importance to the selection of the farm. It should be so laid out and improved as to make a highly organized structure, even though many years must elapse before its completion. One has an opportunity, in opening a new farm, for making a grand monument to his skill or a discreditable showing of his lack of foresight and ability. In assuming the management of an old farm, one can often make changes which will materially increase the comforts, facilitate the daily work, enlarge the profits, stimulate the pride and build up the character of the owner and his family.

Organization of the farm business.—The farm may be looked upon as an organized structure. The windbreaks, public roads, outside line fences, and the inside road and field fences make up, as it were, a skeleton or framework. The buildings, fields and yards are the active organs and the lanes serve as arteries. The main portions of the farm are the farmstead* containing, so to speak, the head and heart; the fields, acting as stomach and lungs; and the lanes, serving as circulatory organs.

In the middle northwestern states, and in most other parts of the country, whatever may be the present lines of farming chosen, the foundation plan should be such that stock raising may easily be taken up at once or in the near future, possibly by future owners. This means that in placing the windbreak, the dwelling and other

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*The name farmstead is here used to mean that portion of the farm separate from the fields, chosen for the location of the buildings, yards, garden, orchard, etc., and often in part surrounded with a grove left when clearing, or planted to serve as a windbreak.

improvements, space should be allotted in a suitable location for buildings and yards for the stock and for buildings for the storage of feedstuffs.

The general plan should be so made that the stock barns and yards may be directly connected by lanes with the various fields of the farm. If stock farming or mixed farming is not to be at once entered upon, the ultimate plan need not at first be wholly developed. Specialized forms of farm management need the farmstead and fields arranged to suit specific purposes. Most farmers, however, are devoted to general farming, with which are dovetailed the production of crops to be sold for money, of forage and grain to be fed to stock, of animals which are reared for sale or for use on the farm for work, for the dairy, or for meat or wool products. Poultry and crops raised for family use, as garden and fruit, are also important products of nearly all well-regulated farms, whether highly specialized or quite general in the nature of crops produced for the market, and space in suitable locations should be given them.

In planning a farm the entire business, including the lines of production, should be decided upon. In only rare cases is it well to limit the production of marketable products to a single line. On the other hand, it is unwise to attempt too many lines. Two to four main lines are usually more profitable than one or many. The advantage of having a few lines rather than one are numerous. The available labor can be more economically used, as one crop will need attention at one season of the year, and another at a different time. Live stock require most labor in the winter, when other farm enterprises demand least, and thus aid in economically utilizing labor the year round.

A combination of specialties may be selected which will thus furnish labor profitable employment at all seasons of the year. A few lines can be so mastered that the farmer can become a specialist in each, thus enabling him to pursue those lines at an advantage over persons who are less expert. It pays the farmer to equip himself thoroughly with modern appliances and materials in the few enterprises in which he risks his success, and to make a thorough study along those lines. There is not only more certainty of success, but more satisfaction, to the man who tries to know his lines of work more thoroughly than anyone else. One specialty necessitates "carrying all the eggs in one basket," and should prices be low, the season unfavorable, or should other misfortunes befall this one industry, the loss is felt most keenly.

There are few single lines of farm production which may be so managed as profitably to utilize labor steadily throughout the year. On the other hand, too many lines result in the business being so indefinite and poorly arranged, that none of the numerous lines may be studied and followed up and by years of accumulated experience and equipment made a success equal to the best. The management of labor cannot be systematized, as there are liable to be too many things to be done at once. Too many irons in the fire result in some being burned, and, while giving a few saving blows at those that are suffering, the most important projects are not pressed forward to a profitable completion.

The business plan should be stable.—Changing from one line of farming to another, with temporary changes in prices or profits, is most unwise. Steadiness of purpose, determination to stand by the ship, is a quality as necessary to success in farming as in other business affairs. During every year in which a given line of production is pursued, there is some experience gained, and usually the farm equipment for this particular enterprise grows. Much is lost both by abandoning the preparation made to carry on the old line and in gathering together the knowledge and the materials necessary to inaugurate the new.

If one has a few principal lines, he may cater somewhat to prices in choosing the relative energy and time to devote each year to the respective lines of production. Prices depend so much on unforeseen conditions that, at best, something must be left to chance. There are, however, a few simple rules which are worthy of recognition. When the price of a product is abnormally low, it is a far better time to get ready for producing more of it than when prices are high. One extreme follows another in the prices of staple farm products which can easily be produced. Thus high prices for pork usually alternate every several years with low prices. High prices for horses, in like manner, are sure to follow low prices. The length of the periods of change require a longer time with horses than with hogs, because horses will not reproduce in large numbers at so rapid a rate as hogs, and each animal requires several times as long to reach maturity. When prices are very high is usually not the best time to purchase foundation stock for new herds, because high prices are sure to fall. Low prices are nearly always followed by higher prices in agricultural products.

By keeping posted in the lines of production, the farmer can sometimes foresee that there are evidences of a coming strong demand for certain products and a slow demand for other products. One acquainted with the wonderful development of cattle ranches during the decades 1870 to 1890 could not fail to see that the supply of beef in this country was increasing more rapidly than the demand, a condition which always results in falling prices. On the other hand, the fact that prices of beef advanced, rather than fell off, during the financial panic, following 1893, when the people had less money with which to purchase meats, could be taken by the farmer, at the end of the panic, as an assurance that the supply was no longer increasing more rapidly than the demand, and that the supply of cheaply raised ranch beef, as compared with the growing demand, had reached its climax, and that beef raising would be more remunerative. These illustrations are given, not to show that these industries may now be remunerative, but rather to illustrate a principle and to show the advantage of studying in a broad way those factors which modify supply and demand and thus cause irregular fluctuations in prices. Some farmers who have an abundance of the product which may be in special demand, succeed partly because they look ahead and anticipate high prices.

Enterprise brings success.—The farmer has abundant opportunities for the exercise of the spirit of enterprise. If all his neighbors have poor hogs, the most profitable line of production he can enter upon may be the production of pure-bred animals to sell for breeding purposes. To make a success of this, he must carry out his business in a somewhat different way from that which might succeed in simply raising fat porkers for the market. He must secure superior breeding animals and rear their young in the most improved manner. He must create a market for his pigs by educating his neighbors to an appreciation of better stock. Likewise, a farmer may get the best corn, wheat or other crop, and, by raising fine crops of good quality, work up a reputation as a grower of pure-bred seeds and thus obtain from his neighbors prices for seed which are better than the prices offered at the elevator, or even more than could be realized if the grain were fed to live stock. Other specialties which offer opportunities are berry raising, orchard fruits, or even some less common crop with which the local market is not supplied by other farmers in the vicinity. Often the distant market will afford better prices than the home market. Especially in case of pure-bred animals and pedigreed seeds, people will pay better prices for something secured at a distance from their homes. But most farmers must win out by doing ordinary farming very well. The great staple crops and the great classes of live stock are the stay of the farming business, and producing them is a remunerative business if well conducted.

THE FARMSTEAD

Location.—After taking a general view of the farm, the location of the central feature should be decided upon. The farmstead must be so placed as to have a good site and be in easy communication with all other parts of the farm. See sites of farmsteads in Figures 41 to 43 F.

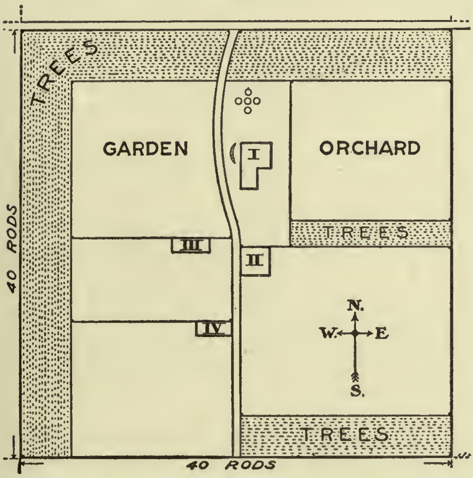

Fig 37. General plan for a farmstead, with road on the north; with windbreak, orchard and gardens; and with buildings, lanes and paddocks or small fields handily arranged beside each barn: I, house; II, horse barn; III, poultry house; IV, cow barn. The south half of the small field beside the horse barn could be used for swine with a building near the central lane, with such division into lots as may be required for the horses and hogs.

Site of the farmstead.— The farmstead should be proportionate in size to the farm and to the farm business, and it may be definite in its outline on at least two sides. So locating the farmstead that it may be enlarged in one or two directions is sometimes an advantage, as when the farm is enlarged by the purchase of adjoining tracts.

Ten acres, or an area 40 by 40 rods, or 30 by 50 rods, makes a very good-sized farmstead on a farm of 160 acres. (See Figure 37.) This allows a distance of 8 to 20 rods between the house and the barn, with ample room for the garden, orchard, lawns and shelter belt on half the area. The remainder can be utilized for barns, food storage buildings, machine sheds and yards for animals. The laying out, platting and staking out locations for buildings can best be done on the ground, and while the owner must decide most of these questions, he should consult with others to secure their criticisms of his plans and suggestions of improvements. After the plan has been decided upon, the necessary measurements should be made and a map drawn showing the proposed location for grove, buildings and other features of the farmstead.

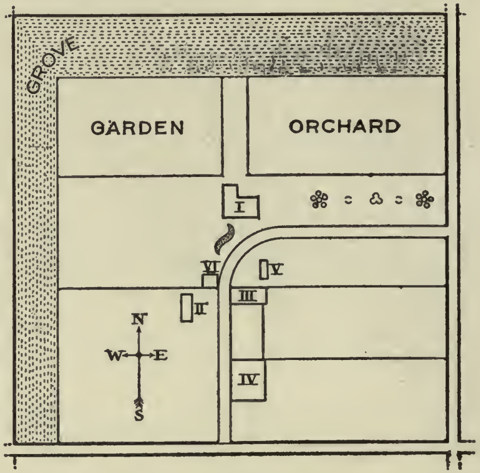

Figure 38. Farmstead on the southeast corner of the farm, fronting east and the land sloping to the east. I, Dwelling; II, hog house; III, horse barn; IV, cattle barn; V, poultry house; VI, grain house. By means of branch lanes from II, IV and V, with cross fences, the hogs, cattle and poultry can be supplied with small fenced fields planted to permanent pasture or used for growing pasturage and soilage in rotation.

Windbreaks and shelter belts.—The location of a grove for a windbreak, and for a background to the picture of home life within, is a matter worthy of careful thought, especially in cold or windy regions. Laying out the location for a timber belt to form two or more sides of the farmstead, as definitely locates the size, form and position of this center of the operations of the farm, as the placing of the foundation and sills of a barn or dwelling decides upon the plan of the building. These foundation plans should be large so that the farmstead may contain ample room for all the buildings, yards and garden plats which may be needed in the future. If there is more land thus inclosed than is needed in the start, one or two small plats or fields can be utilized for special crops. Potatoes, roots for stock, corn or other crops for soilage, or pastures for calves, colts or hogs, may thus be raised to advantage near the buildings. The area within the windbreaks should be large enough so that when the live stock has so increased as to necessitate enlarging the number of buildings and paddocks, there will be adequate room.

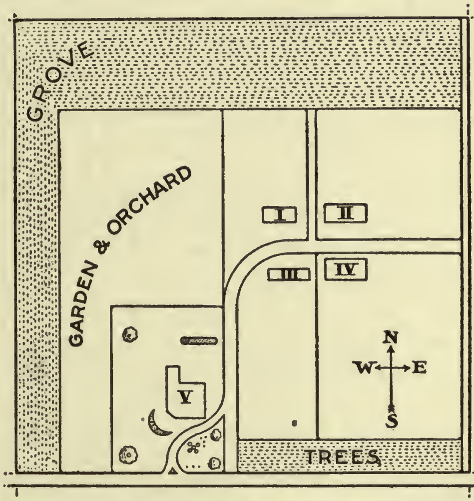

Figure 39. Farmstead fronting road on the south. I, Horse barn; II, swine barn; III, poultry house; IV, cattle barn.

Many farms on the prairies are not sheltered by windbreaks, though ample time has elapsed since they were first established. The dreary aspect, the frigid experiences of caring for stock in winter, the loss of profits on animals from the lack of protection from the sweep of biting winds, the barrenness of the surroundings of the home, are not to be considered lightly. The man or woman who has grown up within a prairie home snugly surrounded by a grove planted early by the father, can best appreciate the difference between that and the unprotected farmhouse. Considered from the standpoint of cost and profit in dollars and cents, the grove pays. If to this is added the comforts, the pleasures, the greater possibilities of having a more beautiful home life, stronger attachment of the children to the home, and better opportunities for developing strong, useful lives, the profits are not easily computed.

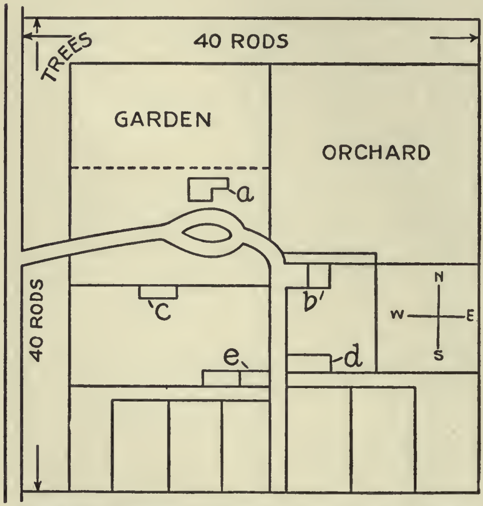

Figure 40. Farmstead fronting road on the west. a, house; b, horse barn; c, poultry house; d, cow barn; e, hog barn.

In the middle northwest, where the prevailing winter winds and cold storms come from the north and west, it is usually desirable to have the windbreak on these two sides, with the south and east open to the warm sun, as shown in Figures 37, 38, 39 and 40. These four plans are designed to show: the general arrangement as to the approach from the public highway, whether it is on the north, east, west or south; the relative location and distance apart of buildings; and the general plans for lanes and paddocks, also the location of the orchard and the gardens. Nearly every farm offers individual problems and only general suggestions can be given here. In some sections, belts or clumps of trees grouped throughout the farmstead for a protection from hot, southwest winds are also desirable and they add beauty. Trees for shade and to reduce the summer temperature of the home often are important, and foresight in planting the proper kinds of trees in the best places is wise. Some farms have been unfortunately planned, and the buildings so placed that it is very difficult to locate groves and clumps of trees where they are most needed. Not infrequently the dwelling or the barn buildings, or both, are located so close to a public road on the west or north that there is no room for a timber belt. A similarly fatal mistake is often made by placing the buildings on the top of a hill that slopes to the north or west. This last arrangement is especially undesirable if the hillside is gravelly or otherwise unsuited to the rapid growth of trees for shelter, shade and ornament.

Farmers who enter timbered lands are too apt to cut away all trees near their buildings. The necessity for removing trees from their fields seems to develop a desire for destroying trees. Many a farmhouse in the timbered regions has been placed on a hill, the trees have been cut away all around, and no protection left on the north and west sides, thus changing a cozy nook into a blank opening, having only a house instead of a cozy home. Trees may yet be planted, however, and the farm made homelike.

It is often an advantage to have the farmstead near a public road, as this facilitates communication with the outer world. The wife likes to have a glimpse of passers-by, and the neighborly call of a friend who can drop in is pleasant to all members of the family. The free delivery of mail and the public conveyance of children to the consolidated rural school, which should be the rule in every farm community, also are less expensive and more satisfactory when the house is not too far from the highway. In some cases old farmsteads should be abandoned and new ones developed in locations more suitable as to topography and soil, and in easier reach of schools, churches, towns and neighbors.

Other timber belts on parts of the farm not adjacent to the buildings are often desirable on prairie farms, and

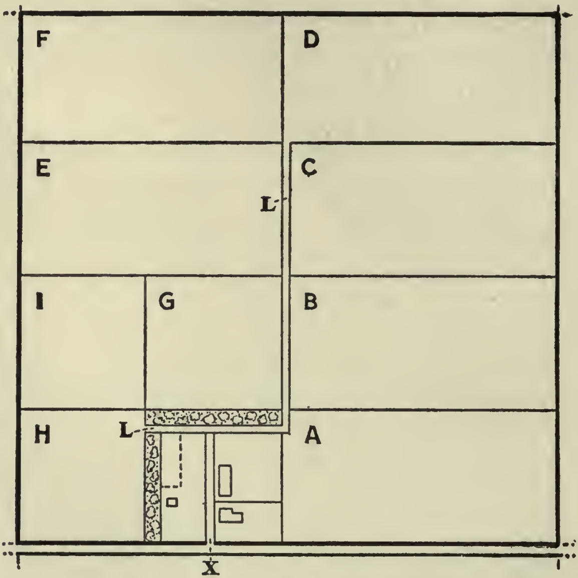

Figure 41. Plan of a 160-acre farm with six twenty-acre fields and three ten-acre fields, while ten acres are devoted to the farmstead. The lane LL, with its branch X, connects the public highway, the barn buildings, the paddocks, and all the fields with each other. The plan is so made that all the fields may eventually be fenced and used under two systems of crop rotation as shown more in detail in Figure 42; on the six larger fields, A to E, is a six-year rotation; on the three smaller fields, G, H, I, is a three-year rotation.

efforts should be made to preserve carefully some of the best areas of woods on timbered farms; and to manage properly under a good plan of forest cropping the growth of timber on sandy, rough or stony lands, where lumber, fuel, paper, pulp or other forest crop, may pay better than ordinary grain crops, or pastures, or hay.

Roads and lanes.—These are mentioned in connection with the plan of the farmstead and the fields. The public road, whether it forms a boundary of the farmstead or is reached by a road or lane across the farm between fields, should be connected with the dwelling, the barns, the lanes among the barnyards, and roads reaching all the fields. Much time may be saved by a convenient arrangement of lanes and gates among the buildings and yards. A day, or even a month, of careful planning may save years of needless work and worry, and will do much toward providing for a permanent healthy interest in the farm work.

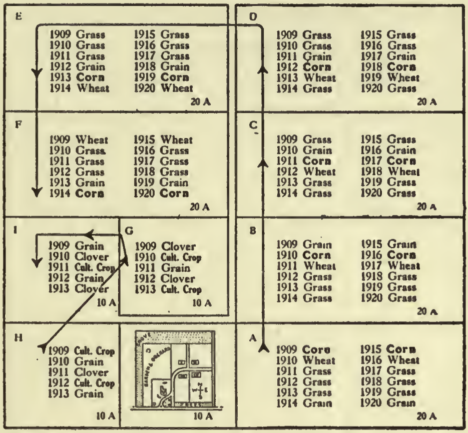

Figure 42. Giving method of writing, in a simple map of the farm, a rotation scheme showing the crops to be grown in each field for a long series of years, in fact, a permanent projection of a cropping plan for systematic rotation in each field of each rotation series. The arrow shows the order of succession in which the six-year rotation is begun with **corn** in the six twenty-acre fields and the three-year rotation is begun with **cultivated crops** in the three ten-acre fields. A rotation suitable to the six twenty-acre fields in the middle northwest is as follows: 1st year, corn; 2d year, wheat; 3d year, grass; 4th year, grass; 5th year, grass (or grain); 6th year, grain; then, beginning again with corn, repeat. By starting out with one field, as A, with corn in 1909; field B in corn in 1910; field C in corn in 1911, etc, each field takes its regular place in the rotation course, giving annually 20 acres to corn, 20 to wheat, 60 to grass and 20 to other small grains. A rotation suited to the three ten-acre plats is as follows: 1st year, cultivated crops; 2d year, grain; 3d year, clover. To show that the order of numbering or the order in which the fields occur need not be followed in any regular way in deciding which field shall first be planted to a given crop chosen to begin the rotation, the three-year rotation is placed on fields G, H and I in an order which does not seem regular on paper, but might be the most natural order in which to bring the fields from an old system of cropping to the new rotation scheme. The arrow here also shows the course of the rotation.

Paddocks and barnyards.—The central feature of barnyards and paddocks should be a lane communicating at one end, by means of gates, with the stock doors of the barns, with paddocks, yards and side lanes, and, at the outer end, with the lanes leading to the pastures and other fenced fields of the farm. Though this artery be very simple and inexpensive, yet it will save many steps and make gentle treatment of the stock possible. Substantial fences may now be made so cheaply of smooth woven wire that no stock farm should lack a handy arrangement of paddocks with lanes and gates.

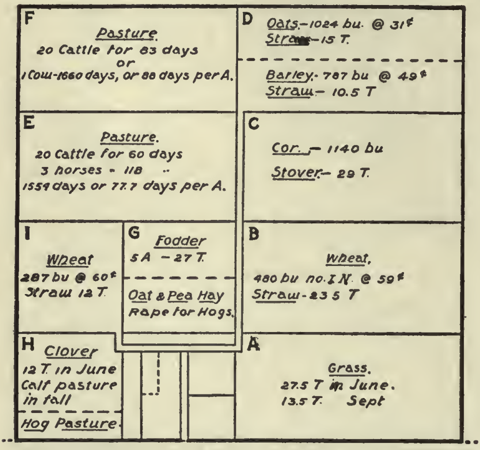

Figure 43A. Shows a map on which the crops grown on each field for a given year (1911) are recorded, together with a record of the yield of each crop, etc. It will be observed that these are the crops prescribed for the year 1911 in the rotations projected in Figure 42.

Lawn, garden and orchard.—The lawn, the garden and the orchard should each be given room in the original plan of the farmstead. The orchard should be so placed that the air will not remain quiet among the trees but will drain out, thus tending to reduce injury from bacterial and fungous diseases and to make the trees less subject to injury from frost. A northeast slope, with trees on the north but none on the east, often best combines shelter from winter winds with air drainage. In some cases it seems best not to surround the plat chosen for an orchard with the grove, or else to place the orchard on the north or east side of the grove.

Buildings for specialties.—Buildings for propagating plants, for manufacturing dairy products, for making sugar, for drying fruit, for meats or other special purposes, should be so placed as to be convenient.

Cellars and caves should be handily arranged that they may be easily entered in winter. Cellars under living houses are far too common, as they are not easily kept wholesome, and sometimes endanger the health of the family.

The residence.—The buildings should not be too near a public highway. Five to fifteen rods from the road is a good distance to place the dwelling on the family farm, while the barns should be in convenient communication with the house, as well as properly located for protection from cold winds and for drainage. The residence should be so placed as to be easily reached from all other buildings and yet afford a pretty lawn and a commanding view of the farmstead. It should be substantially built, with attractive exterior. The general architectural features should be made comely by their general proportions rather than by means of fancy scroll work, or other designs which will not long endure or may not be cheaply kept in repair. While the permanent business of the farm may not warrant a large or expensive house, whatever is built should be as substantial and enduring as can be afforded. The buildings are like the well-cared-for soil, or a well-made road, a

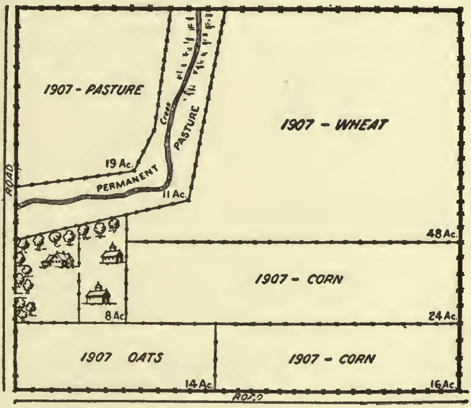

Figure 43B. Olson Farm (one hundred and forty acres) before replanning.
NOTE. The land inclosed by fences overflows, and can best be used as permanent pasture. The remainder of the land is all rich, gently rolling, and suitable for corn, grass and grain crops.

permanent portion of the capital stock. The outbuildings, such as woodshed, ice house, etc., may often be utilized by building them near together, to inclose or shelter a court or yard in which the wood cutting and many other outdoor duties may be performed in comfort, even on cold days.

The barn buildings.—The buildings for animals and feedstuffs should not be too near the residence, because of the odors, and the litter which is usually scattered about at harvest time. Neither should the distance be too great, especially in cold, windy countries, where the numerous daily trips between the house and barns should not be unnecessarily long. There are many arguments for

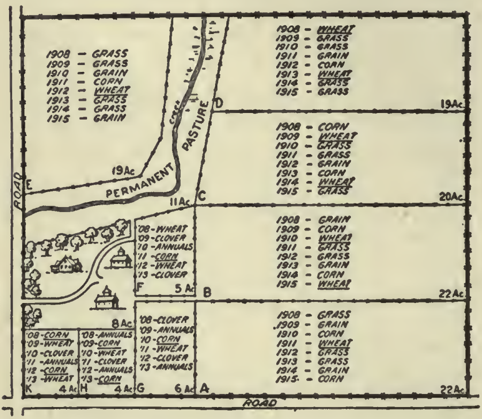

Figure 43C. Olson Farm. Reorganized plan.
NOTE. Five-year rotation on five twenty-acre fields: First year, wheat; second year, grass; third year, grass; fourth year, grain; fifth year, corn.
Four-year rotation on four fields of five and six acres each: First year, corn; second year, wheat; third year, clover; fourth year, plots of annual pasturage and soiling crops, to be used with movable fences for separately fencing each portion as ready for pasturing.

having one large barn and centering there the live stock and their foods. In developing a farm, however, the means with which to erect buildings are not earned at a bound, and, as a rule, it is necessary to erect one building at a time. It is not a bad plan, as it can be afforded, to build well a separate building for each class of live stock. The barns, machinery sheds, and other sheds and granaries may often be used to inclose yards, in which the stock may be comfortable when out of doors in winter.

The fields.—A complete inspection of the farm is necessary, in selecting one to purchase, and it should be even more complete when deciding on the general plan for its development. Lands which cannot be used in arable fields in the general scheme of the rotation must be set aside for meadows, permanent pastures or wood lots. In considering these in connection with the several fields into which the arable portion should be divided for the purpose of deciding upon a system of rotating the crops, each should be so arranged that it may be reached through suitable roads and lanes. (See Figure 41.) The fields which are to be alternately plowed and in tame grasses should be three or more in number, so as to make practicable a system of change or rotation which will be at once profitable in the yields of crops, and will aid in keeping up the fertility of the soil. The plan of the fields and lanes should also be platted on paper. This is important, not only to preserve the plan, but to induce one to keep a record of the fields.

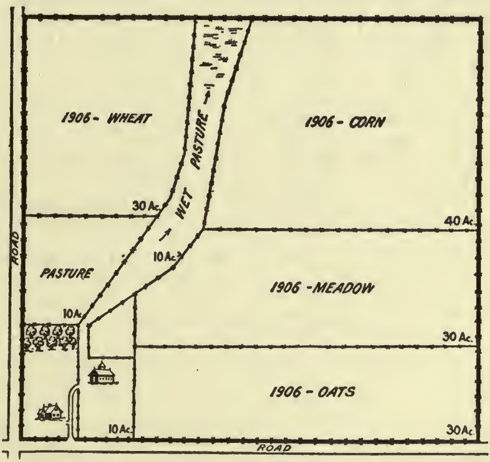

Figure 43D. Harlan Farm. One-hundred-and-sixty-acre farm before replanning. The wet area is to be tile drained.

Provide for systematic rotation.—Every farm business should be planned out years ahead and the plan should be recorded. There should be adopted a scheme of rotating the crops, the general features of which should be adhered to, with modifications in the less important matters as season, market, labor and other farm conditions may require.

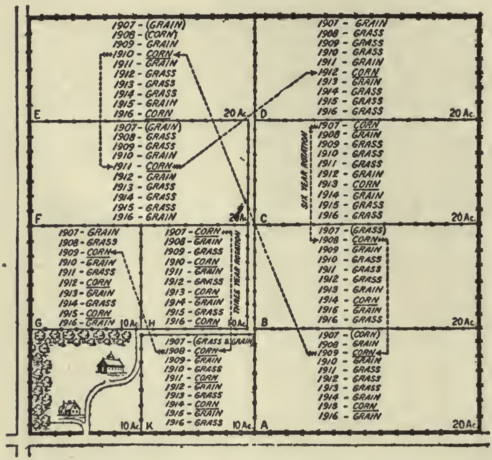

Figure 43E. Harlan Farm. A six-year rotation projected on six twenty-acre fields, and a three-year rotation on three ten-acre fields. The arrows following corn from 1907, on Field C, on the successive fields to 1912 on Field D, shows the arrangement of succession of the fields in the six-year rotation.

The central feature of the field plan should be a scheme of rotation of crops. Most farms should be divided into two portions, and each portion divided into a number of fields of nearly equal size. Some farms should have only one set of fields, and some should be divided into more than two parts, with each part divided up into a series of fields adapted to a given scheme of crop rotation. Thus two fields accommodate a two-year rotation, three fields a three-year rotation, four fields a four-year rotation, etc. Thus about the same acreage of each class of crops is provided each year; also all the advantages of crop rotation to keep the soil productive; and farming becomes an orderly business in which records can be kept and where profits and losses on each enterprise can be more definitely known. That a systematic rotation of crops may and should be planned and successfully inaugurated has been amply demonstrated. A few illustrations of systematically arranged plans for new farms and for the rearrangement of old farms are here given. Those who have become expert in this kind of rural engineering in a given locality have no serious trouble in using the farmer's own knowledge of his soils and of the products he wishes to make, in rearranging and mapping any farm so that the owner can conduct it under systematic crop rotations. This cannot be done at arm's length, as by editors in their offices, but must be done on "the ground," with the plan of the farm, a knowledge of the farm and the farm business in all its details, in mind. Even then, the final decisions relating to the number of fields in the cropping scheme; the sequence of crops; specific plans, as for catch crops; the place for fences; all must be worked out by the farmer, and much of the drawing must be done by him or under his immediate supervision. Often he cannot, and more often he will not, follow a ready-made plan or even a plan which does not comprehend his own best thought. The work of rearranging fence lines, placing lanes, and deciding upon the length of rotations and the crops to be included in each series of fields, requires some skill. A few of the general prin-

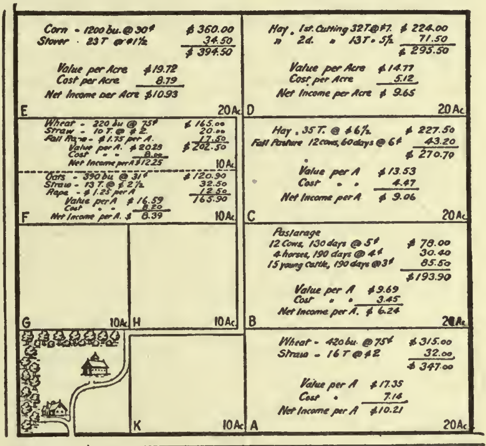

Figure 43F. Harlan Farm. Annual ledger map showing records of crops for 1910.

ciples and facts concerning the rotation of crops may properly be stated here. (See Figures 41 and 43.) It should be observed that the following statements apply somewhat locally to the farm conditions of the middle Northwest.

The average yearly value of the series of crops in rotation must considerably exceed the average cost of production, that there may be a large net annual profit per acre and per worker.

Each crop chosen must do its share toward producing the average net profit by its direct net profit, taking into account the reduction of the productivity of the soil, or its improvement of the soil for succeeding crops.

Soil-reducing crops include most of the grains and cultivated crops. Soil-improving crops include most of the grasses, clovers and such other leguminous crops as peas, beans and lupins.

Some crops reduce the productivity of the soil for the same and certain other crops, while some crops increase the productivity of the soil for certain crops. Thus wheat, oats and barley reduce the productivity of the soil for wheat, oats and barley. Corn, on the other hand, leaves the soil in peculiarly favorable condition for these small grains, and for grasses and clovers seeded with them. Clovers, and the legumes generally, leave the soil peculiarly improved for nearly all crops.

Crops which reduce the productivity of the soil may do so in various ways, as, by allowing to multiply those kinds of weeds which are peculiarly harmful to the succeeding crops; by introducing plant diseases; possibly by introducing substances poisonous to the soil; by leaving the soil in poor mechanical condition; and by leaving it lean of certain compounds needed for plant food.

Crops which increase the productivity of the soil may accomplish this in numerous ways, as by adding organic matter which support bacterial and other activities; by supporting bacteria which bring into the soil atmospheric nitrogen; by providing a good seed bed; by opening up impervious subsoils by the roots; by improving the mechanical conditions of the furrow-slice so that it may be put into better tilth; and by increasing the farm supply of manure.

As a general rule cultivated crops prepare the immediate conditions of the land for the grains; grains for the grasses, especially where the grasses are grown the first year among grain crops; and the grasses, in turn, prepare the land for cultivated crops, as in the following rotation: First year, corn; second year, wheat; third year, clover; and repeat indefinitely.

All the crops in the rotation should be in practical sequence, as: First year, corn; second year, wheat; third, fourth and fifth years, timothy and clover for hay and pasturage; sixth year, grain. Here the corn prepares the land for the wheat, and also provides a solid furrow-slice with mellow seed bed, suited to insure a catch of timothy and clover seeded with the spring wheat; the wheat gives a profitable crop, while the clover and timothy plants have a year in which to start among the wheat so as to yield well the third year; the grass sod provides splendid conditions for the oats, barley, flax or other grain grown in the sixth year; and after receiving part of the year's product of stable manure, the grain stubble, plowed in either fall or spring, puts the soil in splendid condition for the crop of corn, with which the rotation is again inaugurated.

This rotation scheme includes crops each of which gives a large average net profit; requires the expense of plowing each field only twice in six years, once for the corn and once for grain; keeps in check weeds and plant diseases; maintains a good percentage of organic matter in the soil; provides for a high annual rate of plant food production from the soil and from the air; maintains the soil in good condition mechanically; leaves the land more productive at the end of each six-year rotation period; keeps down the requirements for present day high-priced labor; and, for the region mentioned above, it is the basis of a system of crop and live stock production which yields a high annual net income per acre and per worker.

Most farms are rather awkwardly organized, many of them not showing any attempt at systematic planning. It is hoped that investigations, in crop rotations, in the cost of making farm products, in the methods used by the most successful farmers, and other like subjects, will ere long give a basis for a literature on farm organization and farm management in each state.

When this has been done the farmer, often with the help of his son and the teacher in the consolidated rural school, can place on paper a systematically organized plan to be followed in its main features. Keeping an annual ledger map by annually putting yields, cost and other facts in each field on the map, will be a pleasant task for the farmer. Duplicate copies of these maps on file in the consolidated rural school, in the agricultural high school, and in the agricultural newspaper, will be the bases of very lively discussion of farm management. This subject will then have changed from an indefinite, if not uninteresting, topic to a fascinating and most vital educational and economic subject.

CHAPTER VIII

SUBDUING THE LAND

In subduing the land we meet a variety of problems. The labor, time and expense of subduing the native grass sod on a field of undulating prairie land is not more than double the cost of plowing under the stubble of one crop, preparatory to planting another. Where the land is wet and part or all the field must be drained, there is a material addition to the cost; and often much time must elapse before the soil is drained and ready to receive the seeds of a cultivated crop and bring in returns for capital invested in the wet acres. Where brush, trees, stones or even coarse peat are present, there is an added outlay of labor required, and the date when profits may be realized on the land is still further delayed.

A large portion of our wooded lands has rich soils free of stones, and is well adapted to use as arable lands in rotative cropping. Much of the land covered with native trees, however, is rough, stony, wet or otherwise not adapted to the use of the plow, and would best be used for permanent grass land or for the continued growth of forest crops.

Brushing the land is usually the first operation in forest-covered land, that there may be little to impede the operations of grubbing, and that the piled brush may be dry and useful in aiding to burn the stumps. In new districts, remote from large centers of population, much good wood, and even straight timber sticks, must be sacrificed to the flames because of the too great expense of transporting them to market.

The brush scythe, a light ax, a hand brush hook, and simple devices for using horses for raking the brush together into piles, are the implements chiefly used in

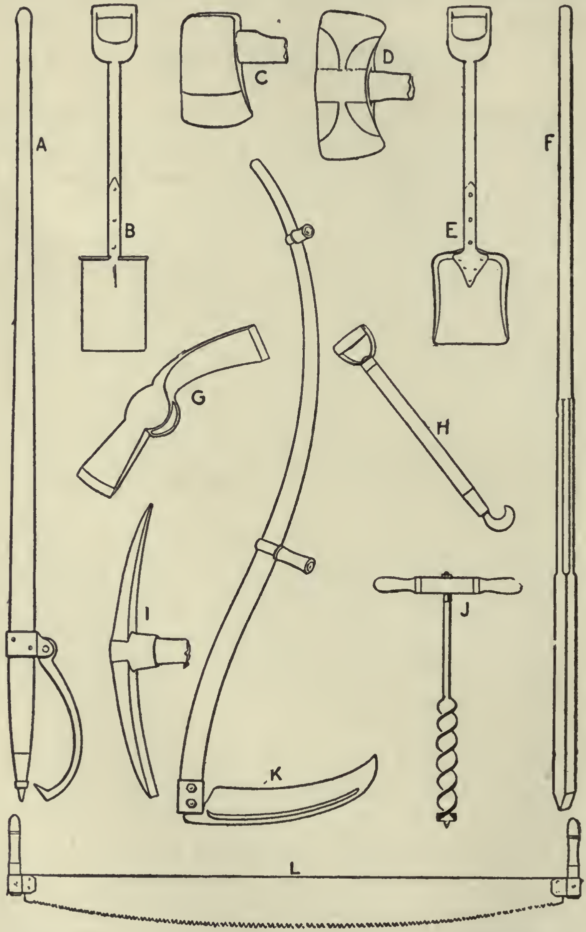

Figure 44. A, canthook; B, spade; C, poll ax; D, double-edged ax; E, shovel; F, crowbar; G, mattock; H, brush hook; I, pick; J, auger; K, brush scythe; L, cross-cut saw.

clearing the land of shrubs and of brush left from fallen trees. In this, as in other operations of clearing, there is use for skill and judgment as well as for an abundance of brawn. For the heavy work of drawing together logs, a team, preferably one experienced in logging, and an equipment of chains, canthooks, etc., are very necessary; while human muscle, coupled with skill and tact, are

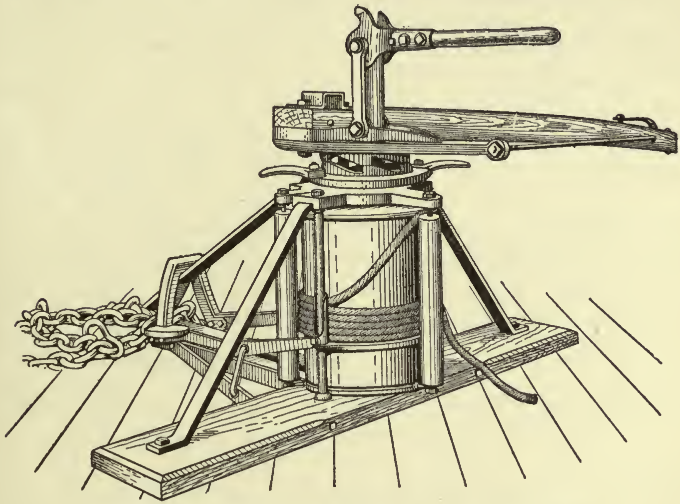

Figure 45. A useful form of windlass or capstan stump puller.

also required for rapid and thoroughgoing work. It is necessary to precede the skidding of logs with some ax work, in case of recently felled trees or tops from which the branches have not yet rotted; and following the skidding, the ax and brush scythe are used to remove the shrubs and trees which are too small to require grubbing. Where not too remote, and where herding or fencing can be arranged, sheep and goats may sometimes be employed in brushing the lands, provided it is not important to get the land immediately under the plow.

For arable fields all trees and stones should be removed. In some cases the difficulty of removing stones and stumps will not permit the immediate completion of the work. Time allows the stumps to decay and our fungous bacterial friends may be allowed to gradually decompose the roots until the stumps may more readily be removed. Time also gives opportunity for accumulating the means and forces necessary to remove obstacles

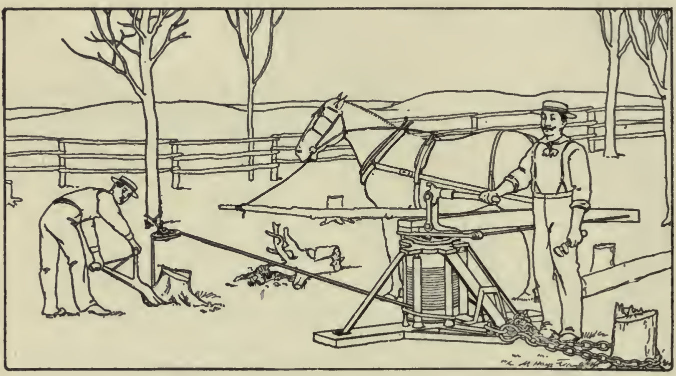

Figure 46. Showing use of windlass and "stump hook" or "root plow."

which could not be removed with the limited resources at first available. Where the stones or stumps are not too thick the cultivation may, in some cases, at least temporarily, be carried on among them. The stump may be removed easier by attacking the roots while the tree is standing, rather than after it has been cut down. Any mechanical device for pulling the stump affords greater advantage if attached some distance up the body of the tree. Usually, however, the lumbermen precede the settler and only stumps remain to be removed.

Grubbing is the heavy and expensive part of the work of clearing. Heavy machinery is being developed for removing stumps, and explosives are useful, yet hand work is necessary, and in rare cases stumps may be best removed entirely by hand. Some of the most necessary hand tools are shown in Figure 44.

The art of digging about the stump with shovel and mattock, of cutting the roots with mattock or ax and of gradually working the stump loose so that it may be displaced, cannot well be learned from the written page. Doing the work, together with the expert advice and counsel of one experienced in the business, is the way this and many other things, consisting largely of manual operations, may best be learned. There is much opportunity for head work, and the man who uses good judgment as to where and how to strike, conserves his strength and makes rapid progress.

Stump pullers are becoming a most useful part of the clearing outfit and are adapted to a large proportion of the work. These machines are of several kinds. Various forms are adapted to multiply handpower. One of the common forms of this type of machine has, as its essential parts, a strong tripod, and a powerful screw worked by a hand lever which lifts the stump, on the same principle as the jackscrew, except that it is used to pull instead of to push.

A short, strong chain, 20 to 40 feet long, fastened to a heavy lever, and a team hitched to the other end, gives power to pull out many stumps, even if they are as large as 2 feet in diameter. A very large pole, 30 or more feet long, with a heavy chain to wrap around the stump, is the usual device. The team pulling on the small end of the pole literally twists the stump loose from the earth.

A block and tackle, applied by means of a capstan, is much used to multiply horse and steam power. The capstan, fastened to one or more strong stumps by means of guy chains or cables, is the main feature of some of the most practical stump pullers in use. (See Figures 45-47.)

Since loggers have successfully adapted steam engines to drawing logs through the woods, invention has been directed to the use of steam power for pulling stumps. The general plan is to use an engine with sufficient power to pull stumps or trees, with a long cable. A horse or team is used to carry quickly the outer end of the cable from the dislodged stump to the one next to be removed.

Recently devised steam stump-pulling machinery promises to reduce the cost of removing stumps. These machines are too large to be afforded by the individual farmer. They may be owned by a group of co-operating farmers, or by persons who operate them for hire. In some cases land dealers use these devices to clear a portion of each farm offered for sale. In the settlement of a new region the land dealer who thus sells partially cleared farms can give employment to new settlers, who in return for part of their wages hire the machine to clear more of their lands. By using only sufficient dynamite to jar the larger stumps loose from the earth, so they may be brought to the burning pile with less adhering soil, the stumps are easily pulled and drawn by the cables to a pile near the engine. Sometimes an acre of stumps are thus placed in one pile at a single setting of the engine. The drum which winds up the cables is also used to draw the engine to its new station. To accomplish this, the cable is attached to stumps in the area to be next cleared and as the drum winds it up, the engine, now made free of its guy cables, travels on skids to its new location.

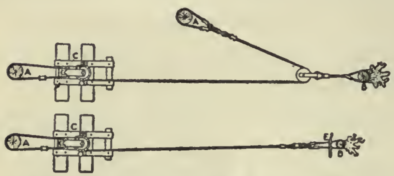

Figure 47. In the lower figure is shown a sectional view of the windlass or capstan stump puller anchored to the stump A, and pulling the stump B, direct. The upper figure shows the use of a single block in doubling the power in pulling the stump B, and utilizing two anchors, stumps AA.

Some stumps may be partially burned by boring a hole from the top of the stump down diagonally through the side, pouring kerosene into this slowly, so as to saturate the walls of the hole, and then applying a match. The hole serves as a chimney to give draft to the fire, which causes the stump to burn. Stumps or logs in the pile which refuse to burn may sometimes be started anew by thus using the auger and a small amount of kerosene. But the more frequent use of fire in removing stumps is to cover them with brush and waste timber and burn part of the stump while burning the other wood. Remaining portions, as large roots, may then be dislodged by pulling them with the stump puller.

The cost per acre of clearing land of stumps varies from a few dollars to a hundred dollars or more. The kind of growth, the thickness of the stumps, the kind of soil and subsoil and the value of the wood products secured while clearing the land are the leading items to be considered in estimating the net cost. There is more labor connected with removing stumps from a clay or from a stony soil than from a sandy soil and subsoil.

The species of tree is also a most influential factor in the cost of clearing lands. The poplar stump, for example, is soft, easily broken, and not large, and may be removed when green with comparatively little trouble; and if killed, it will rot in a few years so as to be very easily removed. The white birch, tamarack, basswood and jack pine stumps are also easily removed.

The white pine, on the other hand, grows large, has very extensive though not deeply penetrating roots. It is solid, its wood is full of pitch, which serves as a preservative, and it will remain for a generation and still be hard to remove. Large stumps of this tree often require from one to five dollars' worth of labor and materials to remove them. Some hickories and oaks, develop large stumps with strong tap roots, holding them very firmly to the soil. The wood will last, in case of the oaks, almost as long as the white pine stumps. The number of stumps per acre likewise modifies the cost, as does also the amount of brush and logs, which must be burned or hauled off. The value of logs, cordwood, posts, etc., in some cases may be equal to or greater than the cost of clearing the field.

Explosives used in grubbing.—Explosives are coming into general use in removing stumps. Their use is only in part to throw the stumps out of the ground, the greater aid being to jar the stump loose from the earth adhering to its roots. Stumps which are pulled by mechanically applied power bring up with their roots large quantities of earth which must be worked loose with shovel, and mattock, requiring no small amount of labor, as this earth must be returned to the hole from which the stump came. The stump which has been thoroughly shaken with a charge of dynamite, even if it must then be pulled by the stump puller, usually brings up but little earth. Stumps which are not clean of earth require a long time to dry and additional labor to burn them. Another considerable gain in using a powerful explosive comes from splitting the stump so that it may be more easily handled and piled closer in the log pile, that it may more certainly be consumed at the first burning. Stumps which are pulled up entire are often great sprawling bodies, the roots preventing close piling in the fire heap, often requiring a second or a third piling and refiring before they are all consumed.

The nature of explosives should be thoroughly understood by those who use them that serious accidents may be avoided. Dynamite should be handled with much the same care as would be used in handling eggs. It should be kept cool, yet not frozen, and the sticks of dynamite should be handled gently. For transporting, it should be packed in sawdust or some similar material, which will prevent its receiving sudden jars. When frozen, it should be thawed out slowly and without direct contact with the heated surface of a stove or fuel. Most accidents in cold climates happen while thawing out frozen dynamite. Dynamite is sold in forms so that one or more pieces or sticks may be used for each stump, and suitable fuses are also made. The portions of stumps not thrown entirely out of the ground by the explosive may be drawn out by means of a team with chain and stump hook; though if large roots remain deeply imbedded in the soil the stump puller may be used.

The position in which to place the dynamite must be determined by the form and position of the stump. At the side of and under the stump, in a hole made in the earth with a crowbar, is usually the most advantageous place in case of large pine stumps. In some cases, it is wise to bore a hole in the stump, and, in rare cases, to locate the load of explosive under the center of the stump. In timbered regions where much clearing is in progress, men may be employed who are especially expert in the effective and economic use of dynamite.

Experience with a given kind of stump under certain conditions of soil will aid the judgment of the intelligent man in locating the explosives so as best to throw the stump out, and break it into parts which may be easily piled for burning.

Chemicals for destroying stumps have been experimented with, but so far as known none of them have been successfully used.

Bacteria and fungi perform an important part in the decay of stumps and it has been suggested that the work of the bacteria might be encouraged by inoculating the stump with the proper species, or by supplying them with the kinds of foods or conditions which would cause them to multiply. Forms of fungi perform an important part in slowly removing stumps, and it may be that by mulching or by otherwise controlling the amount of moisture these and the bacteria would be encouraged to do their work more rapidly.

Burning is a convenient method of removing logs, brush and stumps, and the ashes have a value as fertilizer. Some care is required in piling green or wet logs or stumps so that when set on fire they will be completely consumed. Since labor is required to collect and repile the partially burned wood, which is so charred on the outer surface that it will not readily start to burn, the manner of piling the first time is of importance. Waiting until the piled wood has had ample time to dry before setting it on fire is often necessary. Intelligence and care are required to avoid fire spreading into adjoining forests and fields. When the season is excessively dry and the danger considerable it is often best to defer the burning until rains have made the grass and leaves on surrounding lands less inflammable. Skidding logs together, raising them on the heap, and drawing the stumps into advantageous positions for their complete burning requires a constant exercise of intelligence.

Partial clearing for grass lands.—Frequently the expense of removing the largest stumps from a field which is to be cultivated is so great that until the stumps have partially decayed, farmers must farm around them, but the general practice should be, as far as practicable, to clear thoroughly whatever is begun. In "cut over" fields, which cannot be at once cleared of all the stumps, valuable pasturage may be had by clearing out and burning only the shrubs, small trees and down timber. The stumps may thus be left for the rotting process to make their removal easier at a later date. Where there are valuable young trees still growing, these, too, may be left and only the open spaces cleared out to be seeded to the grasses and clovers desired for pasturage. Since these grass and clover seeds should be planted in freshly worked soil and not covered deeply by leaves and weeds, it is wise, in many cases, to choose a dry time and burn the surface over, using care to remove leaves from about valuable trees, thus to avoid their being injured by the fire. Cutting up the surface by means of a spring tooth harrow, or a heavily built and weighted A harrow, or double A harrow, or by means of a disk harrow, gives a place for the grass seeds to germinate. Experience proves that seeds planted in these lands, in northern or drouthy sections, are more certain to germinate and live if planted early in the spring. This gives the roots a strong hold on the soil before hot, dry summer conditions prevail, and the crowns are then sufficiently mature to endure the severity of the first winter. In southern moister sections, early autumn, or even late autumn or winter planting of grasses and clover is sometimes best.

Fire as a means of clearing up timber lands is a very useful and dangerous agency. In very dry seasons great forest fires sweep over large tracts, sometimes covering many townships, and sometimes entire counties are burned over, as in the case of the Hinckley fire in Pine county, Minnesota, in 1894. Immense quantities of timber of more or less value are destroyed, the brush is burned to the ground; partially rotted logs and other forms of " down timber " are consumed. But these forest conflagrations in dry seasons do not stop with the consumption of the useful trees and the useless wood and brush. They burn up the thick mulch of leaves and twigs and nearly decayed matter on the surface of the soil, which would be valuable if the farmer could save it until his plow has turned it under the furrow-slice to become useful in forming fertility. The damage from fire does not even stop here. The heat from the burning wood and leaves penetrates and destroys much of the organic matter already incorporated among the stony particles of the soil, and even injures the mechanical texture of soils already lacking in binding power. The leaves and other forms of nearly decayed plant substances are especially needed by sandy soils, and it is on our light soils that fires most frequently cause permanent loss of fertility. A fire, in a very dry season, will consume all the soil covering which Nature has been slowly accumulating for centuries. Even in heavy soils all the fine humus mulching materials should be carefully preserved and care should be used to select seasons for burning the brush and stump piles when the fire will not burn up valuable fertilizing matter by running over the surface of the ground.

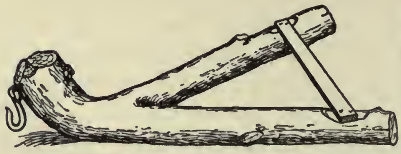
Figure 48. Mud boat.

Removing stones.—Removing stones is largely a matter of main strength. Most smaller stones should be picked from the surface by hand or fork as they are turned up by the plow. The breaking plow by no means brings them all to the surface the first year, but each time the field is stirred with the stubble plow a new crop of stones comes to the surface. The only way to get them all out is to remove them as they are brought to the surface, or uncovered by the plow, and not allow them again to be covered. When there are only occasional stones found, the plowman may carry them to the end of the field in a small box on the plow, but if there are many, a man should follow after the plow, and remove them with the stone boat or wagon. Where the stones are thick, a low wagon is best for stones of

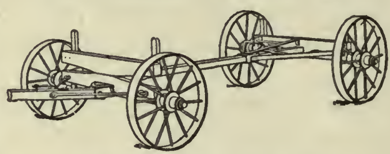
Figure 49. Low or handy wagon.

medium size, and the stone boat for larger ones. (See Figures 48, 49 and 50.)

Machinery and tools.—A two-wheeled cart, made very strong and with wheels of large diameter, is a useful implement for swinging up heavy stones and transporting them. The requirements in the way of tools, etc., for removing and breaking large stones are: Shovels, heavy chains to place about the stones, drills and wedges for making holes and giant powder or other explosives. Drawing the stones out of their settings with a team, like skidding logs, is a matter requiring skill, and also a steady, strong team. Using dynamite laid on the stone or some explosive placed in a drill hole and held down with tamped clay, while a comparatively simple matter, must be learned by experience, else too much expense will be entailed for materials, and there will be too much danger of accidents from the improper handling of the explosives.

Since stones are often useful, they may be drawn to places where they are most available for use. If in large numbers and no immediate use is to be made of them, they should be compactly piled where they will occupy little valuable land, where they will not be unsightly, and in such a manner that they will not harbor weeds.

Uses for field stones.—A limited number of field stones may be found so useful on the farm where rocks from quarries are expensive to secure, that the cost of removing them is small compared with their value. Material for foundations to buildings and for cellar walls may thus be secured more cheaply than from a distant stone quarry. Bridge abutments, stone arches for smaller bridges and culverts, retaining walls, roads and paths, may be made of stones thus collected; and with foresight these may be drawn directly from the field to the points at which they are needed. Stones thus secured are useful for the foundation of roads and walks. Ditches along the roadside, farm ditches through land which readily washes, may be paved cheaply with field stones; and rather than leave the stones in unsightly piles along the roadside or throughout the field, it sometimes pays to pile them up into fences. The cost of wire fences is now so low, however, that the labor of piling up stone fences and of repairing them will not, as a rule, pay in the end.

Removing trees, shrubs and roots from peaty land.—Many swamps are covered with trees. Sometimes a thick growth, as of tamarack or spruce, is formed, which is valuable for posts, fuel or other purposes. Other swamps have scattering trees of small size, and in other cases no trees are to be seen, but underneath the upper layers of peat are encountered stumps, roots and logs which greatly impede the work of making drains and of cultivation. Where fire can be safely used to consume the upper 3 to 6 inches of peat, the stumps and roots of standing or decayed trees thus uncovered may then be easily removed. The roots of trees growing in peat do not penetrate deeply, but spread out almost horizontally. By burning off the covering of moss and peat, the roots and stumps are also burned, or are so exposed that they may be freely lifted out of the peat and removed. Any stumps, roots or stems of trees of a former time which have been covered by the upbuilding of the peat and which impede the plow may usually be drawn out by hand or team. In case burning is not practicable, as where the surface peat cannot be gotten sufficiently dry,

Figure 50. Stone boat.

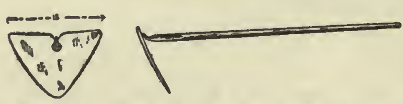

Figure 51. Hook. A kind of large hoe used in Western Germany to upturn the coarse surface peat, in subduing virgin moorlands.

or where it is so dry that there is danger of burning pit holes in the peat, much force and labor are required to pull the trees and stumps out and pile them up for burning. Some care is necessary to avoid burning large piles of wood on peaty soils, as the fire may make the peat beneath so hot and dry that a pit will be burned out, and a fire thus started can often only be extinguished with great difficulty. In peaty lands which are used for pastures, and in some which are used for meadows, the slow process of decay may be allowed to remove stumps and roots. When the peat is drained, and air takes the place of part of the water among the particles of peat, decay goes on rapidly. This is in a large part due to the presence of the myriads of bacteria which thrive in the drier soil and help to decompose the organic matter.

Burning the surface peat as a means of getting rid of the coarse, unrotted, recently formed moss and other forms of plant life, and of securing a finer soil in the better decayed deeper and older peat in which to plant crops, is important. The upper 6 to 10 inches of newly drained peaty land is usually a loose mass of moss and may in some instances be burned off.

Solidifying by pasturing.—Where it is impracticable to burn off or to otherwise remove the surface moss before sowing tame grass seed, it is difficult to secure a stand of grasses or clovers. In many instances where one is in no haste to subdue fully the peaty land, an advantage is gained by having animals pasture on it, and thus compact the peat by tramping. Animals may be encouraged to roam over the fields by sowing such pasture plants as red-top, timothy and alsike clover. This compacting prevents the development of sphagnum or other mosses and forms the surface into a soil-like condition, thus giving the grasses a better chance to thrive.

The packing by the feet of animals often results in the formation of hummocks which make mowing for hay next to impossible, and breaking somewhat difficult. Where the land is to remain for some time in pasture, these objections have less force.

Plowing and pulverizing peaty lands is ordinarily done with the plows, pulverizers and harrows in ordinary use on the farm. Plows might be made that would be especially adapted to breaking such land. The share

Figure 52. Burning surface peat in West Germany where peaty lands are called moorlands.

should be broad, so that a wide furrow can be made, and it should be kept sharp so as to cut off roots. The coulter should be adapted to cut loose the edge of the soft, mossy furrow-slice and to sever all but the largest roots. Where it is desired to use moorlands for pastures or meadows, the complete destruction of wild plants and the making of a smooth seed bed is wise, if not too expensive. Peaty lands once subdued are cultivated with much the same plows and implements used in solid soils.

Growing crops on peaty lands.—In many cases the moorland may be broken, sown to flax or oats, and seeded down to tame grasses, to remain permanently; or the grass sod may be plowed under after several years, one or more crops of flax, oats or other crops grown, and the land again seeded down. These soils are usually best for producing grasses or vegetables, and are sometimes used in the cultivation of celery. But if fertilized, and the drainage and cultivation properly managed, they will produce a number of the staple crops. They are

Figure 53. Placing bog shoes on a horse.

not good wheat soils. Oats thrive better than most grains, and corn for fodder may also be raised on some peaty soils.

Timothy and alsike clover, or timothy alone, will make large yields of hay where the water level can be maintained at a point to keep up the proper moisture supply. Where the conditions are slightly too wet for these crops, red-top will make a good yield of hay of fair quality, and on some marshes too wet for red-top, fair crops of hay from wild grasses are produced. Kentucky blue grass seeds should never be sown on lands designed for permanent meadow, because this grass grows too short for hay; though, owing to its underground root stalks, it can, in north temperate regions, crowd out most of the better meadow grasses, except in very moist soils. The seeds of tame grasses or clover should be sown at the North as soon in spring as the land is dry enough to allow the seeds to germinate. The seed bed is best if made fine and smooth, since this will aid in securing at once a good sod and an even surface for mowing. In many instances it is beneficial to tear up the meadow or pasture sod on peaty lands with the disk harrow, so as to relieve the sodbound condition. While this destroys a portion of the plants, those remaining have more room and respond to the cultivation. This cultivation should usually be done as early in spring as is practicable, or in some cases late in the fall.

Manuring peaty soils.—Extensive experiments at the Moor Experiment Station at Bremen, Germany, show that peaty lands are benefited by complete fertilizers containing nitrogen, potash and phosphoric acid. But it was also found that stable manures are superior to commercial fertilizers for these soils. Peaty lands have an overabundance of old inert humus, but often lack the mineral ingredients, available nitrogen and the easily fermenting vegetable matter of recently applied manures. No doubt, the stable manure, in addition to supplying mineral plant food and nitrogen, brings to the soil many useful bacteria, and possibly a better pabulum of food, for these minute friends than otherwise exists in the peat.

Breaking prairie sod.—The time which vast experience has proven best for breaking prairie land is in the late spring or early summer. During the summer and autumn, the perennial plant stores up in its roots, crown and stems food with which to start its growth the next spring, this food serving the plant much as the stored-up food of the seed nourishes the newly born plantlet. In the spring, after the plant has drawn upon and used all the stored-up food, and before it has had time to lay by a similar supply for the next season, is the best time to kill it. During this stage the leaves are very actively at work, the new growth of roots and stems is succulent, and the plant is in no condition to endure, after being cut in two and turned with its top buried in the soil and its roots exposed to the hot sun. The old portions of the plant are in a weak condition, the new succulent parts have not as yet become hardy and able to withstand rough treatment, and under the influence of the moisture and warm temperature of summer, and with conditions favorable to the bacterial ferments, the sod will rapidly soften and decay. Late in May or June, or early in July, are the best times for breaking, in the middle Northwest, and earlier to the southward. The farmers of each region soon learn the limits of time before and after which the overturned prairie sods do not rot well.

Prairie sods which are tough and strong, rot best if cut only about 3 inches deep, or as shallow as the plow can be made to "swim" and do perfect work. On lighter lands where the grasses grow in bunches without forming a continuous sod, or on prairie lands on which the sod has been killed or much weakened by close pasturing or by the tramping of stock, deeper breaking may be done.

Where heavy soils are broken early and shallow, they may be "backset" in the autumn so as to secure a fine seed bed. In backsetting tough sod, the plow is run in the same direction as the breaker ran, and the furrow is turned back and with it an inch or more of the subsoil. On lands upon which the sods are not tough, the breaking plow or the stubble plow can be run across at right angles with the furrows made in breaking, the sharp rolling coulter being used to cut the sods crosswise. The earth cut below the first furrow is thrown on top by the plow and forms a coating of fine material over the tougher sods, and this loose earth is used to advantage in smoothing the whole into a fine seed bed. Where the sod is very weak and the breaking was done rather deeply, the disk pulverizer, the spring-tooth harrow or even the common spike-tooth harrow, may give a better treatment than to backset, for crops like wheat, which prefer a compact furrow-slice. For the cereal grains, which need to be sown very early, it is often better to complete the preparation of the soil in the fall. While it is customary to leave most newly broken prairie land fallow the first year, it ofttimes pays to sow a crop of flax, millet, fodder corn or turnips; and even beans and potatoes may sometimes be profitably grown on newly broken prairie where the sod is weak.

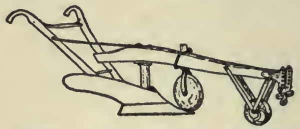

Figure 54. Breaking plow with rolling coulter.

Figure 55. Breaking plow with standing coulter.

Plows for breaking prairie sod are now so perfected that most of the prominent plow firms make breakers suited to each section of the country. For heavy work, and where stones hinder, single walking breakers are used, or the ordinary gang plow is transformed into a breaker by replacing with "breaker bottoms" the moldboards and shares used for stubble plowing.

Plows suited to the work of breaking brush or timber lands are made on a somewhat different plan from those used in prairie breaking. The parts must be stronger, to resist the strains in striking stumps and roots. The moldboard does not need to be so slanting, since there is rarely a tough sod to turn, and the furrow is usually made deeper. In prairie breaking the rolling coulter is often preferred; in timber breaking the standing coulter is generally found more satisfactory. Timber lands are plowed 4 to 7 inches deep. Holes left by the removal of stumps should be first leveled up. The Slush Scraper, the Fresno Scraper, or even the Reversible Road Machine will do this work in many cases much more expeditiously than it can be done by hand.

Mixing sand into clay soils, or mixing clay or muck into sandy soils, is done in some cases, but only where the benefit is very large, so as to repay the cost of high-priced labor. Spreading sand over marshes designed for cranberries, has been found to pay, where the conditions are such that this greatly increases the yields of the cranberries. And in rare cases mucky lands which were too wet for tame grasses, as beside a stream, have been made into very productive soils by the addition of a thin coating of sand. With modern machinery, earth may be moved much more cheaply than formerly, and the ameliorating of inhospitable soils may eventually become more common, though now good lands are so low in price that only for small areas, and for very especial purpose, will it pay to haul heavy earthy materials to mix with the soil. Carting dried peat into barns or into manure cellars, or mixing it directly into the compost heaps, is often profitable, as it decomposes there and aids in conserving the fertilizing constituents of the vegetable manures, and when placed on the land adds somewhat to the humus-making substances.

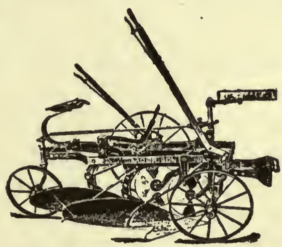

Figure 56. Common gang plow with breaker bottoms.

Alkali Soils.—One of the troublesome and but partially solved problems is the treatment of soils which have an excess of soluble alkaline compounds. Flooding the land, and then drawing off the water after it has dissolved a quantity of alkali, is a plan which has been suggested for heavy, flat lands, but it is not practicable in most cases. Dressing heavily with rotted barn manure has a temporary, beneficial effect, as has also sometimes burning a thick layer of straw upon the soil and thus charring the surface.

Irrigating the alkaline soil with a surplus of water which is carried off by means of underground drains, is an expensive method of leaching out the excess of salts, which is successfully used in some districts where irrigation is practiced. Irrigation may, in many cases, increase the injurious effects of alkali by supplying to the soil large amounts of water which sink down to only a short depth and are returned to the surface by capillary action. Upon evaporation, this water deposits, or leaves, at the surface of the soil, soluble salts which it absorbed from the subsoil. The water in passing down through the soil goes so rapidly that it does not again dissolve all these soluble salts, and thus they gradually accumulate in the furrow-slice, and the roots of the plant are obliged to feed in a soil too strongly impregnated with the substances which, in smaller quantities, would allow them to thrive and grow. Seepage waters coming through pervious layers of earth, from higher areas, and moistening hillsides or lower areas, often, upon evaporating, leave alkaline deposits resulting in "alkali spots." Under-drains and open ditches, to divert the seepage water, are sometimes effective in preventing the accumulation of alkali on the surface or in remedying alkalinity.

Terracing hillsides is sometimes done in fields of considerable size. In gardens it is frequently resorted to, that cultivation may be made easier, to prevent the soils being furrowed out so badly by the waters washing down the hillsides, and as an aid in making it practical to use irrigating waters. In many of the southern states terracing is practiced extensively on the large general fields devoted to cotton, corn and other crops. In many cases where terracing has not been done, the fields are so badly gullied that they are ruined for field crop cultivation. By terracing, the water is conducted gently sidewise and thus carried slowly around the hills and down the slopes, without forming streams which wash out gullies in the easily eroded subsoil.

CHAPTER IX

DRAINAGE

The work of crop production is nearly all concerned with classes of plants which have been evolved through cycles of ages on soils containing only capillary water. Our field crops, garden crops, fruit, forest and ornamental trees are nearly all accustomed to soils in which the ground water does not rise within several feet of the surface. The ground water rising to, or nearly to, the surface, even for short intervals, reduces the yields of many crops. In very few cases, indeed, are the crops made less productive by systems of drainage which rapidly remove all ground water from the soil to the depth of several feet.

Taken in its entirety, land drainage is of vast importance. There are many large areas, in some cases hundreds of miles across, from which standing water must be removed, or which must be protected from oft-recurring flood water. There are large areas, including a few or many farms, for which drainage systems must be constructed by the voluntary co-operation of the owners, or by the county or state, with cost and benefits equalized among the owners. But the larger total of final expense is the drainage within the millions of farms, whether into a natural outlet or into an outlet provided by large community drains.

There is great variety of conditions where drainage will pay, ranging from the deep pond to the hillside which, only in occasional years of unusual rainfall is so wet as to reduce crop yields. The wet sloughs, or bottoms, along streams, the nearly level bottom lands, and the heavy clay lands constitute the bulk of the lands needing drainage; though the ponds, seepy hillsides, alkali areas under irrigation and other minor classes of areas are also large in the aggregate. The values now going to waste in lands which, on account of too much water, are not under cultivation, or are not yielding the full return on the capital and labor invested in their cultivation, is represented by hundreds of millions, if not by billions of dollars, in the United States alone.

The writer knows of no cases where the investment in well-constructed drains, on lands clearly needing drainage, has not proven profitable. On the whole, there has been far too much conservatism in draining out the wet places on the farm, and in co-operative efforts of individuals and public agencies in promoting and building community drains.

There are very few forms of property in which money can be more safely invested than in lands which have been properly reclaimed by drainage. Underdrains of tile are nearly as permanent forms of wealth as the soil itself.

Lands needing drainage.—Those soils need draining which are too wet for the crops we wish to grow on them, though some of these may not pay for draining, especially if they are so situated that the cost per acre will be large. Fields requiring draining may be mentioned under the following heads:

Slough.—Low, flat areas over which the water usually flows in a sluggish manner, seeping through the surface and passing away slowly, are common in nearly all neighborhoods, and many farms have one or more of them. Removing obstructions from the sloughs, or plowing them so as to permit the surface water to flow more freely, will often make these low areas sufficiently dry for the cultivation of crops in rotation or, at least, for the growing of useful meadows of cultivated grasses.

Cultivating lands which drain into sloughs sometimes results in so much less water seeping downward into the slough that it does not thereafter need drainage. The cultivation evidently results in more of the water percolating into, and being stored in, the upper several feet of the surface of fields and being from there transpired back into the air by the rapidly growing plants, which usually are more luxuriant than were the native grasses or other native plants.

Ponds, swamps and sink holes.—Glaciers, in some northern districts, in depositing debris, glacial water in assorting and spreading out the solid materials, and water from snow and rain where there was no glacier, have caused many flat or saucer-shaped places to be formed on the surface of the land. If beneath these low areas there are layers of impervious clay, water accumulates, making them too wet for the growing of cultivated crops. Drainage through open ditches, tile drains, or vertical drains, must be resorted to for the removal of surplus water which accumulates in these places. In some cases these low areas are so situated that drainage is impractical or too expensive to be profitably executed.

Lake borders.—Many lakes are bordered by lands which lie at or very little above the level of lake water. These may be drained by lowering the lake, or, in some cases, conducting the surplus water away from the lake. In many cases it is impractical to drain these lands. The government holds that bodies of water of considerable size belong to the public at large and not to private individuals. When the national government surveys new territory preparatory to its settlement, all water areas of considerable depth and size are carefully surveyed and their borders are accurately mapped by the surveyors. This surveying and mapping is called "meandering," and no one has a right to lower the water in a meandered lake without consent. Where the area of low land lies along the stream through which the lake discharges its supply of water, it is often practicable to construct surface or tile drains which will discharge their water at some point down the stream. Where low areas lie on the side of the lake opposite the outlet, and higher land rises behind them, there is usually no chance for an outlet away from the lake, and owing to these difficulties many of these lands cannot well be drained. Where such areas are large and valuable, however, they may be drained by a system of dikes, drains and pumping machinery, conducting the water through ditches to a low point near the lake, and then elevating it over the embankments by pumps operated by steam or other power. Large areas of land in Holland have been thus reclaimed from the sea, and much more is now being reclaimed at great expense. The streams which pass through these "Netherlands" are conducted to the sea by means of large embankments, called dikes, and not allowed to overflow their banks and thus spread out over the fields, even in times of floods, so that all of the water that it is necessary to pump out over the embankments is that which actually falls upon the land. These flat lands are so rich that this trouble and expense have well repaid the thrifty people of Holland. As our country becomes more densely populated, the areas which we will thus reclaim will increase. The great irrigation projects of the West are bringing us, also, to see that very large diking and draining projects are feasible and may be profitable.

Springy hillsides.—Since the earth composing hills is often deposited in layers, the water which penetrates the soil on higher portions of the land is often arrested in its downward course by an impervious layer of clay or rock. If above the dense stratum there is a layer of sand, gravel or mixed earth, through which the water can seep sidewise, it naturally seeks its lowest level and follows the slope of the layer of clay or stone. If this impervious layer extends out to the side of a hill, the water flows out and spreads through the surface soil of the hillside. Since this flow of spring water is more or less constant, it may keep a considerable layer of the surface of the hillside or level land beyond the hill, or of a depression into which it runs, so wet that there is too much water in the soil for cultivated plants, and only sedges and other water-loving plants will grow. If there is considerable of this water centered in one point, we term it a spring. In some cases the spring water oozes slowly out over a wide area; in other cases it flows gently from one place; and in others it bubbles upward as if confined between an upper and a lower impervious stratum and had broken a passageway through the upper one, and thus finding an outlet had centered in a spring. Some springy hillsides have been so long kept thoroughly saturated with water that the dead roots, stems and leaves of plants have been preserved and a layer of peat has been formed.

Flat lands.—Lands which have not a natural slope are often kept wet by more rain falling on them than runs off or is evaporated. Thus, in Louisiana, a large area of land, made up of deposits from the Mississippi river, is flat and must be drained to be adapted to the growth of cultivated crops. In the valley of the Red River of the North, in Minnesota, North Dakota and Manitoba, likewise, there is a large level area formed by deposits of coarse till and on top of this a fine clay from the great glacier. This was deposited while that area was covered by what is now known as "Ancient Lake Agassiz." (See Figure 7.) In Illinois, Indiana and Iowa, there are large level areas from which the natural rainfall is not removed with sufficient rapidity by natural drainage and evaporation to make them suitable for the most profitable cropping, and in other States north and south there are larger or smaller areas of flat lands which need draining.

Side flooding.—Along rivers and streams there are areas which are subject to flooding by the streams rising and flowing out over the banks. There are other areas where there are no well-defined streams which receive the flood water from the surrounding lands, and are thus made too wet from the lack of suitable channels in which the water can run off. In sections where the drouth is excessive, as in the semi-arid regions of the west, lands which receive flood water have a great advantage, since they are thus naturally irrigated, and in that dry climate the water does not usually stand on them so long as to kill out the plants. But in regions of considerable rainfall, it is generally desirable to prevent water from higher lands flowing over the fields used for cultivated crops, depending only upon the rain which falls directly upon each acre. The Nile valley in Egypt is an excellent example of the lands naturally irrigated and also fertilized by annual deposits of mud.

Localities especially needing drainage.—Some districts need drainage only on small areas, each drain confined to one, or, at most, a few neighboring farms. In other cases the drainage becomes a large problem concerning one or more countries. Thus, in the valley of the Red River of the North, there is a flat area 75 miles by 300 or more, covering several counties in Minnesota and North Dakota, and a large area in Manitoba which need draining of flood water. Here are many conditions which require co-operation of neighboring farmers of an entire township, or several townships, and, in some cases, two or more counties. The problem in that region has been such a large one that the State of Minnesota has appropriated hundreds of thousands of dollars to aid in constructing very large main drains into which the counties and townships may run smaller drains, and with which the farmers, in turn, may connect their farm drains. Even the aid of the United States has been invoked, and there may prove to be sufficient cause for co-operation between the United States and Canada. In northeast Minnesota are large peaty swamps, in some cases covering many thousands of acres. These cannot well be drained by individual farmers, since no farmer can get an outlet unless a general canal is built, into which he can conduct his farm drains. Minnesota, following Illinois, Ohio,* Indiana and other older States, has recognized the need of the county and even the State co-operating with the farmers in constructing large drains, and the State legislature has passed laws under which landowners, townships and counties may organize into associations co-operating in the drainage of large districts.

Cost and profits must be carefully studied.—Where good lands are low in price, drainage must be done at slight expense per acre to justify the investment. On the other hand, where the lands are valuable, considerable expense may be put into open and tile drains and a profit made from the investment. In most cases draining of the really wet lands can be done for a sum far less than the increased value produced. Surface drains can often be used to reclaim land, the increased value of which will represent many times the cost of the drain. In some cases a single drain will carry the water off, or keep it off, a large area, as in a wide slough; while in other cases, in sections where there is a heavy rainfall, open or tile drains are necessarily placed close together. Since tile draining is quite expensive, it usually pays only where the drained lands are relatively high in price,

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*The revised drainage law of Ohio is regarded as being a model of its kind; under it great drainage projects have been put into operation at a remarkably low cost and with equitable adjustment of both public and private interests.

$40 per acre or upwards. There are practical cases, however, where tile drains pay on cheap lands, as where one line of tile will carry off the water from a large area. The judgment of an expert is often worth securing to determine whether the probable profits will be sufficient to warrant the expense of a drain, as well as to plan the proposed drain.

How to determine where drainage is needed.—The farmer who sees his lands from season to season can determine the injury to crops, or the difficulty of raising desired crops on any wet areas. The purchaser who would estimate the need and the probable cost of drainage on lands which he desires to purchase, must depend largely upon inspection and upon the credited statements of those who have observed the land for a series of years. If there is water on the surface, if wild plants which grow only upon wet soils are found, or if there is other evidence that the soil is not suitable for those crops which thrive best on arable land, the need of draining is easily seen. In some instances useful facts can be learned by making holes here or there with a spade or a posthole auger, and observing, from time to time, the height of the ground water in these little wells. By studying the soil throughout successive seasons, important facts may be learned. Where the land is in cultivated crops, or even in tame grasses, the effect of the water in doubtful areas may easily be studied as affecting the health and yield of the crops. Most domesticated plants growing in soil containing more water than they need become yellow, do not grow luxuriantly and yield but little, and sometimes are killed.

The area of the watershed which discharges its water over any given area must be carefully determined and taken into consideration in determining whether the land needs draining, so as better to estimate the amount and influence of the flood water. Sometimes a simple drain may divert this water so as not to necessitate the draining of a large area.

The stratification of the soil where spring or seepage water occurs should be studied when practicable to do so. This can sometimes be done effectively by making holes several feet deep in the wet area with a posthole auger.

Lands not needing drainage.—Where Nature has so formed the surface of the ground that the excess of water easily runs off, or has put together the particles of the soil and subsoil so that the water can readily percolate downward, there is usually nothing to be gained by a system of drainage. Hillsides with open subsoils do not need drainage. In localities where there is not a very large amount of rainfall, drainage has very little effect, even in heavy soils on hillsides.

Level lands through which water can easily percolate do not need artificial drainage, since the drainage downward is sufficient to carry off the excess water. It is desirable for the water to seep through the soil, rather than to run over its surface.

Heavy lands in dry climates, whether rolling or flat, usually do not need draining, or only a sufficient amount to prevent flooding in case of unusual storms. Here it is desirable to let the water from rains lie on the land for a short time, giving it an abundance of time to be absorbed, and preventing as much from running off the surface as possible. The soil and subsoil are great reservoirs which must be relied upon to store up water to be used during periods of drought. In regions of slight or irregular rainfall, it may be advisable to risk the crops suffering some during wet periods, even if the water stands on the fields. This water will go deep into the subsoil and be held available for crops at a future time.

Drainage and rainfall.—The greater the rainfall the greater need there is of drainage. In western Dakota, Montana and other semi-arid districts, drainage is very seldom a problem, except as a mere adjunct to irrigation on the relatively small areas where water for the irrigation can be secured. Most of the denser lower lands require either surface or tile draining in regions of much rainfall, and some of the more dense soils, even on the hillsides, are benefited by removing their excess of water. In England, where the rainfall is heavy and the proximity to the ocean keeps the air moist, thereby decreasing evaporation, a large portion of the land may be drained with profit. There, even the hillsides, if the soil is at all close in texture, will produce better crops if well tile drained. In countries, such as portions of Italy, where the rainfall is three or four times as much as in the Mississippi valley, the drainage must be very complete. The land is ridged so as to carry off as much of the water over the surface as is practicable, and tile drains are used to remove the surplus water from the subsoil, even in soils not very dense.

The benefits of drainage are apparent in many ways. The individual farmer is greatly benefited, and the neighborhood is often made more healthful; and with the better profits in farming the entire community and the state are built up. Elliot, in his book "Engineering for Land Drainage," says that in one Indiana township especially needing drainage, averaging for five years before drainage and five years after drainage, the yield of wheat was increased from 9½ to 19¼ bushels per acre, the yield of corn from 31¼ to 74¼, and that the physicians' books showed 1480 calls to visit malarial patients for the five years before, and only 490 cases for the five years following drainage. Thus the yields of crops were doubled and the malarial cases were divided by three. Many individual farms are changed from malarial to healthful homes by draining out swampy areas. The development of our country means a healthier as well as a richer people.

The effect on the soil is shown in various ways.—Planting and cultivating may be done earlier in the spring, which will insure to crops planted in due season their maturity before early frosts. Drainage also gives the farmer a longer time in which to do his spring work. Drainage holds the soil open to the circulation of the air, so that oxygen and other gases may act in preparing the soil for the plants. Drainage greatly lessens injury from "heaving." In Ohio and other states, where the peculiar clay soils greatly expand or "heave" upon freezing, causing the winter wheat, rye, clover plants, etc., to be broken off from their roots, and the crops thus injured, drainage removes the excess of water and the soils do not expand so much.

Not the least among the benefits of drainage is that it opens the soil to the entrance of the air and makes it a better and more healthful home for bacteria, and for plant and animal life in general. Drainage adapts soils to a greater variety of crops, and a rotation of several crops is known to be more profitable than the continuous planting to one crop. Drainage helps to bring the farm up to that ideal which enables us to grow, under systematic rotation plans, those crops which combine to make the farm the most profitable.

Increase of certainty and quality of crops.—Poorly drained lands are usually low lying, and are, therefore, fairly moist, even in dry years. In wet years, if drained properly, these rich lands raise superior crops.

A more profitable use of fertilizers is brought about by draining the land in such a way that there is only a proper amount of capillary water in the soil and that there are healthy crops to make good use of the land. In case of the application of expensive commercial fertilizers to the land, the above is an important consideration, and especially so in case of crops which require a large amount of expensive hand labor and which must yield a large income per acre to pay a net profit.

The land is tilled with more ease and with better profits if the excess of water is removed. Draining out narrow sloughs, low places inside the field, low areas adjacent to other lands, all benefit the farm lands. The fields can be made more nearly rectangular, which will admit of easier access and of more systematic methods of rotation and cultivation. All parts of the field become sufficiently dry and ready for cultivation in the spring and after rains, at one time, thus making it possible to employ labor economically and to cultivate the soil at a time when its tilth will receive the greatest beneficial effect.

Water flowing from the mouths of tile drains or in open drains may often be conducted to fields or barnyards, there to be a source of water for live stock, or to be used for irrigating field, garden or orchard crops.

The appointment by President Roosevelt of a commission to report on the use and improvement of our internal waterways, and the reclamation of wet lands, may lead to engineering enterprise in drainage, even more gigantic than any yet undertaken in this country. The discussion of drainage by the agricultural and special drainage journals of America demonstrates the great interest our farmers are taking in this practical question. The making of open ditches has passed from the stage of making ditches with the spade to one of constructing small and large canals and dikes by means of machinery. The making of underground ditches has rapidly passed from the making of covered drains by using stone or boards, to drains with factory-made cylindrical or nearly cylindrical tiles most carefully placed in the ground, sometimes by means of tile-laying machinery. In some states, as in level, wet sections of Indiana and Illinois, there are numerous tile factories in each county, and the farmers there have gradually laid tiles on acre after acre until nearly the entire wet area is underdrained, transforming both the agriculture and the sanitation of entire counties. While machinery for laying tiles has been highly developed, for many conditions the spade continues to be the chief implement in opening tile drains.

Injury of tiles by freezing.—In the southern half of the United States there is no danger of frost injuring tile drains. In the extreme northern portions of the country, however, where the earth sometimes freezes to the depth of six or eight feet, the question often arises whether tiles laid two to five feet deep will be ruined by the frost. Where an outlet can be secured so that the water will run freely from the properly laid tiles, there is little danger that sufficient water will remain in them to break the tiles by its expansion under freezing. Where the outlet must be very low, sometimes beneath the water in a pond or stream, the tiles may be full of water when the ground freezes, and in this case its expansion within the tiles may cause them to be split. This may also occur in case the tiles have not been laid on an even downward grade, so that the water will not run out of the low sections of the drain. Likewise, where the tiles have been laid in peaty lands which, upon drying out, shrink and settle more in some areas than in others, thus making the line of grade uneven, freezing may work injury. The actual places on record where freezing of water within the tiles has caused them to crumble down and become clogged up and useless, are, indeed, very few, even in states as far north as Minnesota. No doubt, in many cases, where the water upon freezing expands within the tile causing it to break, it simply cracks lengthwise, or a number of cracks are produced in such a manner that the pieces all remain in position. The expansion of the ice does not usually cause the pieces to spread far enough apart to allow them to fall in and obstruct the water. They are held in position by the weight placed upon them by the surrounding earth as the stones in an arch are held.

Drainage legislation.—Along with the development of the theory of drainage, of drainage machinery and of drainage work, there has been a development of laws relating to the subject. Since the flood water and the drainage water run from farm to farm, it ofttimes happens that one man cannot drain his land unless his neighbor allows him an outlet, or, perhaps, joins with him in making a system of drainage including the wet lands of both farms. In other cases, numerous farms are concerned in one system of drainage. A common ditch may be required to carry off the water from the several farms. This requires concerted action, since it is unfair that one, or even several, of the number interested should bear the large initial expense which should be shared by all who are benefited.

Most of those states in which considerable drainage is needed have devised laws under which a majority of the landowners in any area needing drainage can, under the law, bring about co-operation of all landowners in the payment of the expense of general drains. These laws are made to operate through township or county officers, usually through the boards of county supervisors or commissioners. Those landowners who desire the drain may present a petition to the board, which decides whether the project shall be undertaken, and, if so, arranges to carry forward the work and assesses the costs to the respective landowners. The law designates that a certain area be surveyed, and, if it be found practicable, drained under the drainage law. Generally the board is required to appoint viewers, and to supply them with the services of a competent drainage engineer. These viewers take into consideration the need of the drainage, and after having made a plan of the drains, estimate its cost and apportion the cost to the various persons interested. In some cases the apportionment of the cost is left until the drains are complete and the actual cost is known. The apportionment of the entire cost is made among all the farmers in proportion to their respective benefits. In rare cases the construction of a large drain injures a portion of the land through which it passes, and in such cases damages may be allowed. In cases where individual landowners feel that they have been assessed for more than their just share of the cost of the drains, they may appeal to the board of county commissioners for a reduction. In case of failing to receive what they consider justice, they may appeal to the proper court, which, upon hearing both sides, makes its decision as to the actual amount of the total expense which the appealing landholder shall be required to pay.

As a rule, the board of county commissioners has charge of the construction of the drain. They may revise the plan of the engineer, readjust the findings of the viewers, as to the boundaries of the drainage district and as to the proportion of assessment against each benefited landholder. In many counties the boards of county commissioners issue bonds with which to pay the expenses of the drainage, and when the drain is completed, require the proper county officer to assess the entire cost of the drain upon the owners of the benefited land. Where the drain is constructed under a contractor the board of county commissioners appoints the county engineer or some other competent person to superintend the work of the contractor, under a properly written contract and specifications, that the work may be thoroughly carried out. In many counties the board of commissioners employs a superintendent of construction and supplies him with laborers and materials. In some cases the county assumes the entire or partial cost of drains, and in other cases the state furnishes part or all of the means with which to carry out a large amount of drainage work. Wherever the county or state furnishes part of the means for constructing the drains, it wisely retains at least partial supervision of the expenditures and of the future maintenance of the drains.

Private drains.—Legal questions often arise in making private drains. As a general legal proposition, no one has a right to interfere with natural drainage in a way that shall injure the property of another. Thus, no farmer has the right to discharge the water from a drain upon the land of another in such a way that the flooding of his lands shall be increased or occur at a different time, or in a different place, than would naturally occur. Neither has one person the right to make embankments to prevent his own lands flooding and thereby retard the water flowing naturally from the fields of his neighbor. Bitter litigation and neighborhood quarrels of a most disagreeable and disastrous kind often arise from the failure of neighbors to adjust properly these matters of drainage in a friendly and peaceable manner. In matters of this kind, there is entirely too much effort to get the better of the neighbor, or too much anxiety lest the neighbor get the advantage. It is far wiser to concede much more than is fair than to become involved in a quarrel, and possibly in legal difficulties, which will destroy the peace of the neighborhood, and surely cost both parties many times as much as either one would have had to sacrifice in effecting a peaceable adjustment. Arbitration is becoming much more popular in the world, and here is one of the places where it should nearly always prevail in case of disagreement. Persons asked to serve as arbitrators in difficult matters of this kind have an opportunity to do a patriotic service, not only to the parties involved, but to the neighborhood, and they should courageously accept the responsibility and try to bring about an adjustment which may reasonably satisfy both parties. Laws encouraging, or almost enforcing, arbitration in such matters would be largely useful and should be devised and enacted. A normal public sentiment which would almost force people into arbitration would make for harmony and civilization.

SURVEYING AND MECHANICAL APPLIANCES

The making of drains is an engineering problem and the theory must precede the practical work. The plan should be carefully devised, that the work, when completed, may be effective. The drains should be so located that they will conduct the water from all portions of the wet areas. They should be placed at the proper depth, and have the proper grades, so that the water will run evenly and be carried rapidly to its destination. The number of drains or branch drains should be sufficient to carry off the surface water. They should be placed at that depth which will effectively improve the soil, but not so deep as to make the construction of the drains too expensive.

If the system of drainage is very simple and the slope of the land ample to give sufficient fall, the plan may be easily made. In many such cases instruments for measuring and leveling are not necessary. The farmer's knowledge of the land, or even a "bird's-eye" survey may be sufficient. In other cases, the system may be very extensive, the grade very slight, the expense large and the need of accuracy imperative. Here the assistance of a competent drainage engineer with his measuring and leveling instruments, and his methods of calculation should be employed. He should have a practical knowledge of the local rainfall, ability to estimate the flood water which must be taken care of, an intimate acquaintance with the character of the subsoil, experience in calculating and in judging what size to make open ditches and what size of drain tiles to use.

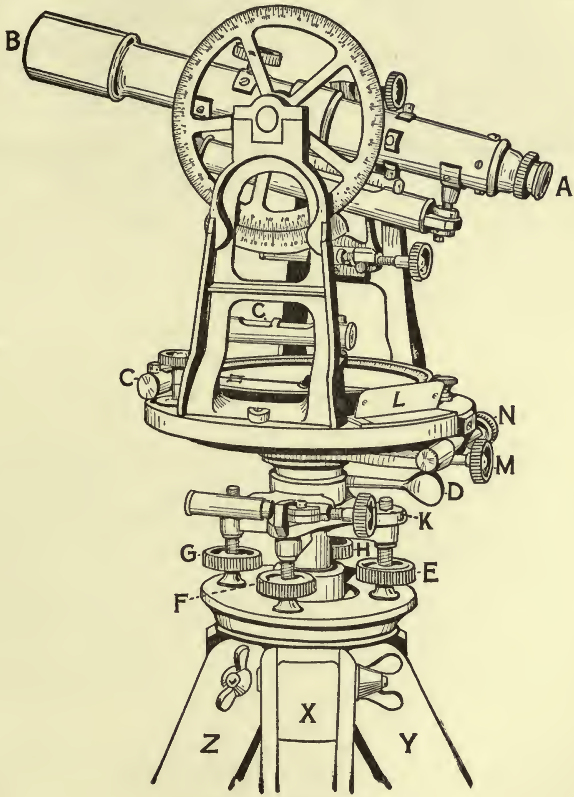

Figure 57. Surveyor's transit.

He should also have tactful ability to deal with the parties interested in co-operative drainage, and this is quite as much needed in the enterprise as his technical knowledge.

Surveying instruments.—In planning drainage requiring the services of a competent engineer, a number of instruments are needed. These are illustrated in various figures accompanying the text. Notes under the figures describe the instruments and give some instructions as to their use. The farmer needs to know more of the

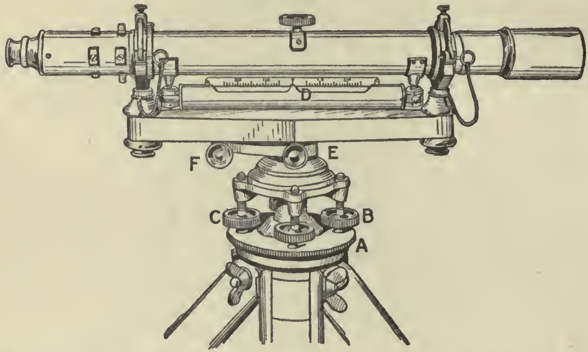

Figure 58 shows a 20-inch wye level, such as is used by engineers for railroad surveying, wagon road surveying and in all drainage surveying where great accuracy is required. The instrument is mounted on a tripod and the operator spreads the legs 3 feet apart, more or less, to bring the telescope even with his eye when slightly stooping. The tripod should be so adjusted that the plate A is in a nearly horizontal position. Turn the telescope so that it rests above two opposite thumb screws, as B, C. With the thumb and forefinger turn these two screws both toward center or both away from center, until the bubble in the spirit level is in the center at D. Now turn the telescope at right angles to its former position so as to be above the other two thumb screws. Turn these screws until the bubble indicates that the telescope is again level. It is wise to turn the instrument the second time over B and C to see that its adjustment is level, and in the course of taking levels the bulb should frequently be inspected and leveled up, especially if the tripod is not firmly placed on solid ground, or if the tripod or the instrument has been in the least jarred out of its position. The use of the set screw at E is to restrain the telescope from revolving and the alignment screw at F is used to make slight changes in revolving the telescope in line with a leveling rod or with a desired line of stakes upon which levels are to be taken.

engineer's technique, that he may better understand the work and that he may be more liberal in employing the trained engineer when needed.

The transit is necessary in planning large drainage enterprises. It is used in locating the line and in determining the angles at which branch lines leave the main lines. The use of the transit is not very difficult for one who has a knowledge of algebra, geometry and trigonometry, and even persons with only a knowledge of arithmetic, with a moderate amount of technical instruction, can make use of it to a limited extent. It is an instrument for the use of the engineer, however, rather than for the use of those who are not specialists in the line of surveying. Transits, such as professional engineers use, are scientific optical instruments of a high order and are expensive, costing about $200. There are cheaper instruments, and also less expensive combined forms of level and transit for the use of farmers. These cost about $50. The farmer who has been well trained in an agricultural school, or who has otherwise learned the use of surveying instruments, can do his own work in small drainage projects cheaply and well. By means of the transit a permanent record may be made, showing on a plat of the land through which drains pass the exact location of the drainage lines. In most cases such records and plats may be made from measurements without the use of a transit.

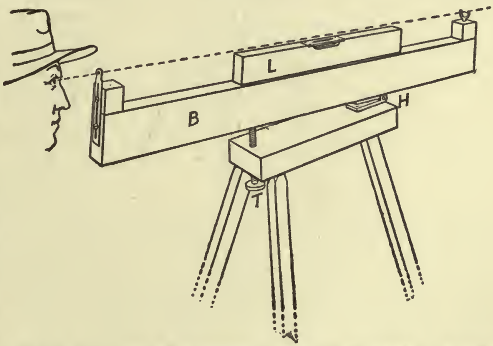

Figure 59. Leveling instrument on which sights are attached to a common pocket, or better, a mason's spirit level. T, thumbscrew; H, hinge.

A map or drawing of the system should be made, locating section corners of the government survey, where that is practicable. Points or lines from which to measure the various lines of the drains, and their point of junction and their extremities, may be definitely located in relation to certain natural objects or artificial monuments, as the lines subdividing the section, or monuments marking the corners of farms and recorded in a drawing or drainage map. By placing the distances and angles on this map, any underdrain can be located at any point at any future time, by again measuring from the given points and base lines. (See Transit in Figure 58.)

Leveling instruments are even more generally useful and necessary, in planning and constructing drains, than the transit. Very often they are necessary to aid in getting the general level of the land so as to determine where to locate the drains so as best to reach wet areas and carry off the water in the most effective manner with the minimum cost of construction. For example, in the Valley of the Red River of the North a drainage engineer was employed to lay out a general plan of drainage. The land was so nearly level in an area 40 by 100 miles that, with his assisting engineers, he surveyed east from the Red River of the North through this district, taking the level at every section corner and also at half mile posts along all east and west section lines. When all this had been done, the figures representing the height of each point above datum plane* were recorded on a map of the entire territory. By examining these figures, the engineer was able to map out all the low areas through which large drainage canals were needed to

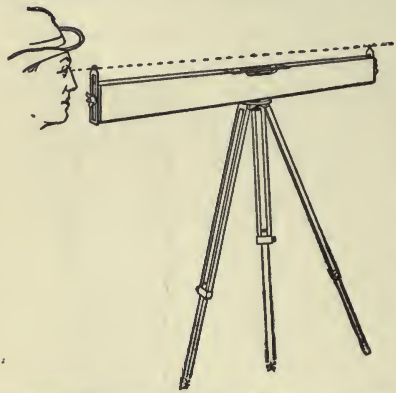

Figure 60. Mason's level placed on tripod and supplied with sights.

*A datum plane is an imaginary level plane used as a basis for comparing the heights of points at or near the surface of the ground. It is usually assumed 100 or 1,000 feet below some stated point or sea level.

give an outlet for smaller canals and for needed farm and roadside ditches.

A general map thus made was published in a pamphlet and has been of great use to the counties, townships and farmers co-operating in the drainage of these lands. A copy of a portion of this map is shown in Figure 70, page 167. In some low areas of much less size, even in single fields, it is necessary to take levels at various points, or, as the engineer says, "cross section the field," so as to map the contour or elevation of the entire area and thus decide where drains are necessary and practical. The level is a necessity also in determining the rates of fall and the grades that should be given to the ditch or tile drain where the grades are so nearly level that they must be very accurately made. It is often needed, while constructing the drain, to see that the bottom of the ditch is at the right depth at the various points. For draining small areas it is often unnecessary to use an expensive instrument, as the home-made instruments shown in Figures 59-61, may serve the purpose.

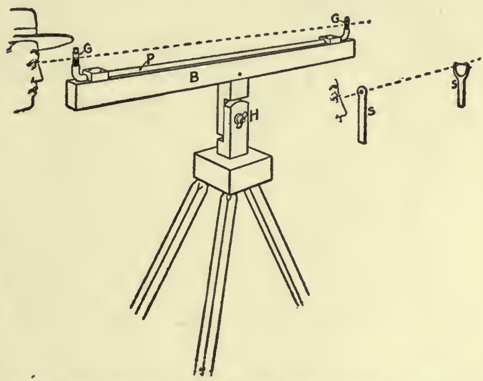

Figure 61 represents a simple form of home-made leveling instrument which is useful where great accuracy is not required. P is a tube of tin or of gas pipe. At either end of the tube a glass tube, G, a few inches long, is inserted. Colored water is poured in so as to rise nearly to the corks in the tubes. A front and a back sight, as SS, or another form of sight, may be adjusted so as to be easily placed level with the top of the colored liquid in either glass tube. At H is shown a form of joint in the stem connecting the level with the tripod. With this the instrument can be placed so nearly level that the water stands at the point desired in each glass tube. This level does not require adjusting, but it is not accurate for long distances on drains which are nearly level, though in the hands of a careful man it may be found useful under circumstances where a better instrument is not available.

Chains, tapes, rods, stakes, etc.—The surveyor's chain, folded, is shown in Figures 63 and 64. Chains are usually four rods (66 feet), sometimes 100 feet in length. The surveyor's band chain of steel is shown in Figure 62. It is now commonly used by engineers, being made lighter and more accurate than the steel chain.

Note books and blank forms.—All measurements and surveys should be accurately recorded in such form that they will not only be useful in planning and constructing the drain, but will serve as a permanent record. If the drain does not work properly, some fault in the figuring or calculations may be found, in which case the records will be useful. Should the drain at any time get out of repair, the original notes may be useful in its repair or reconstruction. Notes of the location of underdrains are especially valuable as permanent records for use when wishing to locate obstructions in tile drains. Figure 81 gives a form to be used in recording the levels taken in finding the best course for the proposed drain, as well as the date used in making calculations for its grade and depth. Furthermore, in making the drain, the level is used in checking for the depth of the ditch at various points along its course. An indexed notebook, 4 x 6 inches, ruled as in Figure 82, is a good place to keep the original notes, including the calculations.

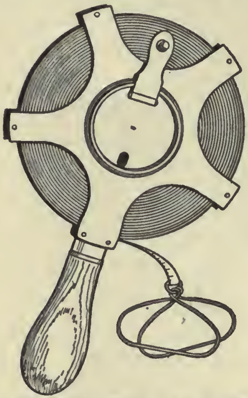

Figure 62. Band chain of steel graduated either in feet or in links, at the ends in tenths or in inches. In use it is entirely detached from the reel. It has handles similar to those used on chains. It is not so convenient as the link chain, but is accurate, even serving as a standard with which to compare the link chain, that its length may occasionally be tested, and, if necessary, corrected.

Drainage plats show methods of making drainage maps. A drainage map of a portion of the valley of the Red River of the North is shown in Figure 70. The figures at the government section corners, giving elevations, show the very level character of the land. The central portion is a great swamp area six by fifteen miles in extent. The proposed ditch, A B, collects a "lost river," which was spread out through the low area into a large swamp. The proposed ditches, C D, E F and G H, are designed to serve as main channels to carry

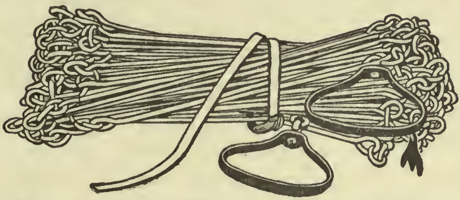

Figure 63. Surveyor's chain folded. Very desirable form of chain in weeds, across streams, around curves, and for general work. Often incorrect in length, and for accurate work should be compared with steel tape.

Figure 64. Surveyor's chain partly folded.

the water toward the Red River. Tributary to these main ditches are roadside ditches along the section lines and ditches across some farms. These farm ditches are here usually made broad and flat with reversible road machines. Into these roadside and farm ditches, dead furrows are made to lead at frequent intervals, by so laying out the plow lands as to place the final furrows in favorable places to lead the water off the fields and into the field, roadside and main ditches. In case of low places a few inches to a foot below the general surface and from a rod in diameter to many acres in area, they are drained by special ditches into the farm ditches. It is often necessary in late fall or in early spring to open out all drains by removing weeds and dust, or earth, that has blown into the ditches or has been washed in, that the water may move quickly out of all low places, thus allowing the soil to dry out for early planting in that cold climate.

Figure 65. Draw pin used to mark a chain length in chaining over a field.

In Figure 72, dotted lines show tile drains on a large flat area, in a moderately open subsoil, in a region where the rainfall is 30 inches per annum. In case wet years show the need in given areas, additional drains can be laid between those provided in this plan. At A and B are tile drains under the center of the roadbed in the flat area. These connect with the main tile ditch at X.

Figure 73 shows the plan used in draining a tract of 480 acres in Iroquois county, Illinois, which is generally level, but was, before drainage, diversified to some extent by ponds which contained water during six months of the year. The grades upon which the drains were laid were, in some cases, one-half inch to 100 feet, varying from this to two inches to 100 feet. The object of drainage was to fit the land at a minimum of expense for the production of hay and grains of various kinds. It should be observed that the drains were staked out in a systematic manner. As shown on the plan (Figure 73), each line is designated by some name by which it is distinguished from others. Its length, as well as its junction with other lines, is indicated by the station number or the number of feet from the outlet point, in each case. This plan also illustrates various methods of location and arrangement of drains ordinarily required. The drains of this tract have been in successful operation for fourteen years, with

Figure 66. Alignment rod. One foot sections alternately red and white.

no repairs or stoppages of any kind during that time. The land is an open black soil with joint clay subsoil which drains quite readily. The final outlets, as shown, are open ditches leading to the larger water course.—After C. G. Elliott.

Machinery and implements.—Much improvement in machinery and implements used in the construction of drains is constantly taking place. There are many situations in which machinery cannot be economically employed and hand labor must be resorted to. Thus in peaty lands where roots obstruct the drainage plow the earth must be thrown out of the open ditch by means of hand tools. Likewise in lands where stones are encountered and in short ditches where the introduction of machinery is not profitable only hand tools are practicable. But in the free soils of most bottom lands of the upper Mississippi valley and other localities, machinery, operated by horses or oxen or even by steam, may be effectively used.

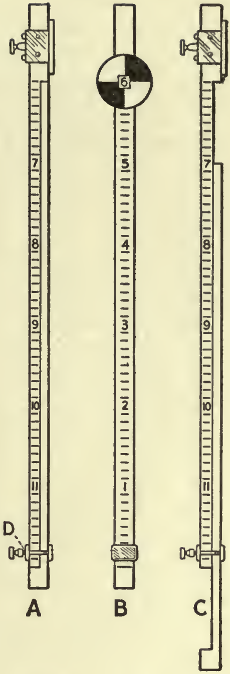

Figure 67. A, side view of leveling rod closed up, for taking measurements of points not far below the line of sight. B, front view of rod closed up. When the rod is closed the figures are read on the front side through the hole in the disk. Figures show the height to which the disk has been raised to be in the line of sight with the eye at the back end of the telescope and with the horizontal cross-wire. C, rod opened up. The disk is now set at the top of the rod. and the adjusting done with the set screw at D. Figures are now read on the side of the upper section at the upper end of the lower section of the rod and from top down.

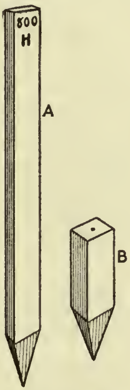

Figure 68. A, grade stake to set beside the ditch. B, hub to be driven with its top even with the surface of the ground beside the tall stake, A, to serve as a constant point upon which to rest the leveling rod in cases where great accuracy is required.

Drain tiles.—Extensive experience in America has led to the adoption of the cylindrical drain tile. In Figure 74 are shown drain tiles of the various sizes, from 2 inches to 12 inches in diameter. Other forms have been recommended at various times, but there is apparently no advantage of these forms over the cylindrical, while there are some manifest disadvantages. Straight tiles, 3 to 12 inches in diameter, are usually made one foot long, but occasionally in two-foot lengths; while 12 to 24-inch tiles are made in two-foot lengths. Tiles with a shoulder (as shown in Figure 75), made like sewer pipes, are manufactured in two-foot lengths, of all sizes.

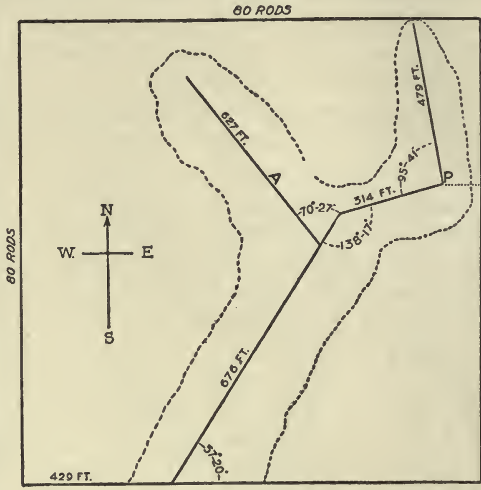

Figure 69. Map of drains. A simple plan of mapping to record the location of a tile drain and its branches, giving the lengths of the lines and the angles of divergence is shown in this figure. The location of outlets and of the points of intersection of tile drains may also be shown on a map by means of measurements from the sides of the farm or from other permanent points. In some cases it is practicable to mark an intersection of drains by a permanent monument, as by a large stone nearly buried.

Drain tiles are made of clay similar to that used in the manufacture of ordinary brick. The clay or mixture of clay and sand must be of a nature to "burn" under high heat in such a manner that when the tiles are exposed to the action of moisture and frost, they will remain intact and not scale nor crumble. In nearly all parts of America where drainage has been needed, clays have been found which can be manufactured into good tiles. The manufacture of drain tiles requires considerable skill as well as a due amount of business ability. Some experimentation is necessary in making drain tiles from any untried bed of clay. Chemical analysis is a general guide as to whether the clay is of a suitable

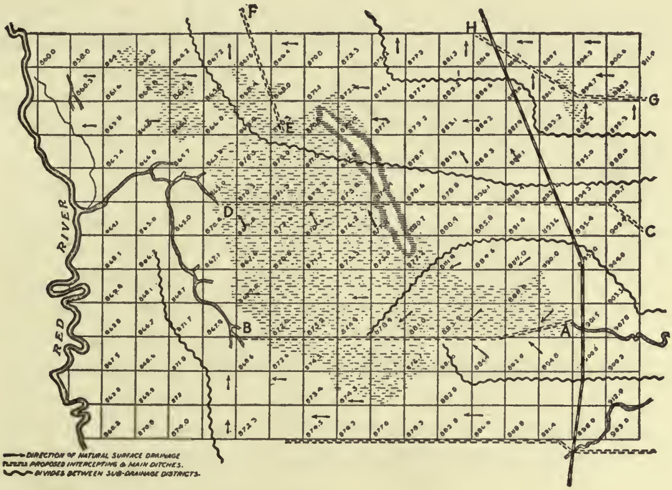

Figure 70. Portion of a drainage map.

nature to "burn" and not be broken to pieces by the action of the atmosphere nor by the freezing of the water absorbed in the body of the burnt tile. It is always wise to ship some of the clay to a factory already established and have it tested, with a view of finding methods of preparing and burning it, before going to the expense of building a factory beside a given clay bed. Very often it is necessary to mix together the surface soil and a layer of clay lower down. In other cases, a layer of mixed sand and clay found near at hand, when put with the clay from the main layer, will give a mixture of the right quality. In still other cases, a mixture of pure sand with the clay is an advantage. All this experimenting incurs expense and should be done by persons who have a knowledge of the business.

Often tile factories have been built where it has been found impracticable to make good tiles from the available clay, and thus a serious loss has been incurred, both to the promoters of the factory, and to the farmers who need, in their vicinity, a factory from which they can get tiles at a reasonable cost and without the expense of long railroad, water or wagon transportation. Tile factories properly inaugurated and operated have usually been profitable, and there are many new sections in need of factories to supply drain tiles with which to improve the large areas of wet lands. In some sections of Minnesota, for example, the farmers buy tiles from factories so far distant that the cost of railway transportation is greater than the cost of the tiles at the factory.

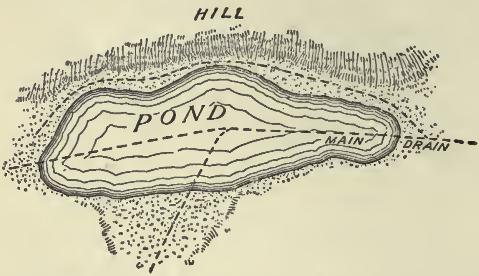

Figure 71. Drain through pond, with lateral on right to intercept seepage water from hillside and another on left to drain a flat area.

Cost of drain tiles.—Under the conditions of labor at the beginning of the twentieth century, three-inch and four-inch drain tiles have cost, at the factories where large quantities are made under favorable conditions, in the neighborhood of $9 and $13, respectively, per thousand feet. The table on page 169 shows, relatively, the average cost, weight, etc., of drain tiles, as given by a manufacturing firm near Elgin, Ill., for the several sizes ordinarily made from 3 to 15 inches in diameter.

Price list of drain tile

Diameter inside measure	Price per 1000 feet	Branches, each, cents	Area in inches	Weight per foot, pounds
3	$10.00	12	7	5
3½	12.50	14	9½	5½
4	16.00	15	12½	7
5	22.00	20	19½	9
6	30.00	25	28½	12
7	40.00	25	38½	15
8	50.00	30	50	18
10	75.00	40	78½	24
12	130.00	80	113	32
15	200.00	95	178	46

15 in. tile 2 feet lengths; all other in 1 foot lengths.

These figures were only general, and were subject to a 10 per cent discount, and since the weight of the tiles depends upon the character or specific gravity of the clay from which the tiles are made and also upon the thickness of the walls of the cylinder, they must not be taken to apply to particular cases. Where one wishes to figure the cost of transportation on tiles from any given factory, he should learn the exact weight of the tiles of that particular brand or make. In sending some distance for the tiles, quotations should be secured from the railway or water transportation company for the rate per ton for freight; or the different factories bidding on bills of tiles should be asked to quote prices, including the freight, at the farmer's home station.

Quality of drain tiles.—There is a great difference in the quality of drain tiles from different factories, and even of the individual tiles from the same factory or kiln. In ordering, one should buy by sample, or on the guarantee of a reputable firm. Where the purchaser can visit the factory, judgment can be passed on the quality of the tiles. They should be straight and square on the ends so as to come close together in the ditch. When two tiles are knocked together, they should have a clear ring. Cracks in a hard tile are objectionable, but much worse is the quality of scaling or crumbling. The presence of lumps or flakes of lime which will slack when wet, causes tiles to disintegrate and become worthless. Questionable tiles may be tested by placing them where they

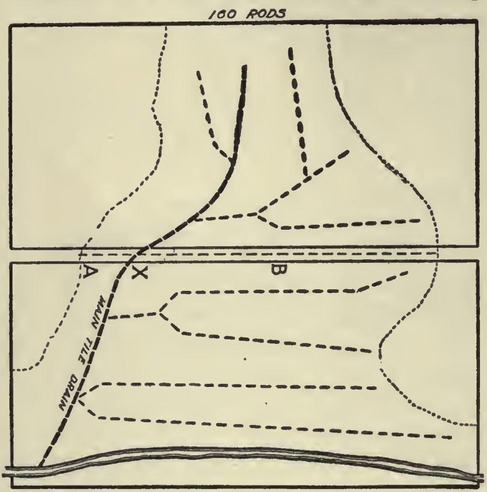

Figure 72. System of tile drains on a 160-acre farm.

can be partially covered by water during winter and allowed to freeze and thaw repeatedly. Tiles that crumble by springtime when treated in this manner are not suited to tile draining, especially in a cold climate.

The best drain tiles are thoroughly vitrified throughout, showing that there has been some fusing or melting of the clay under the intense heat of the kiln. Many manufacturers glaze their tiles, just as the old-fashioned stone milk crock was glazed, by placing salt in the kiln. If the tile is properly burned, glazing adds little or nothing to its value, though the cost is inconsiderable. The fear entertained by some that glazing retards the flow of water through the substance of the tile into the drain tile, is not well founded. Little water goes through the body of any properly made drain tile. There is ample room for the water to seep through between the ends of the tiles, and practically all of it enters at these places. It is also proven that nearly all the water enters the tile at the lower half of the

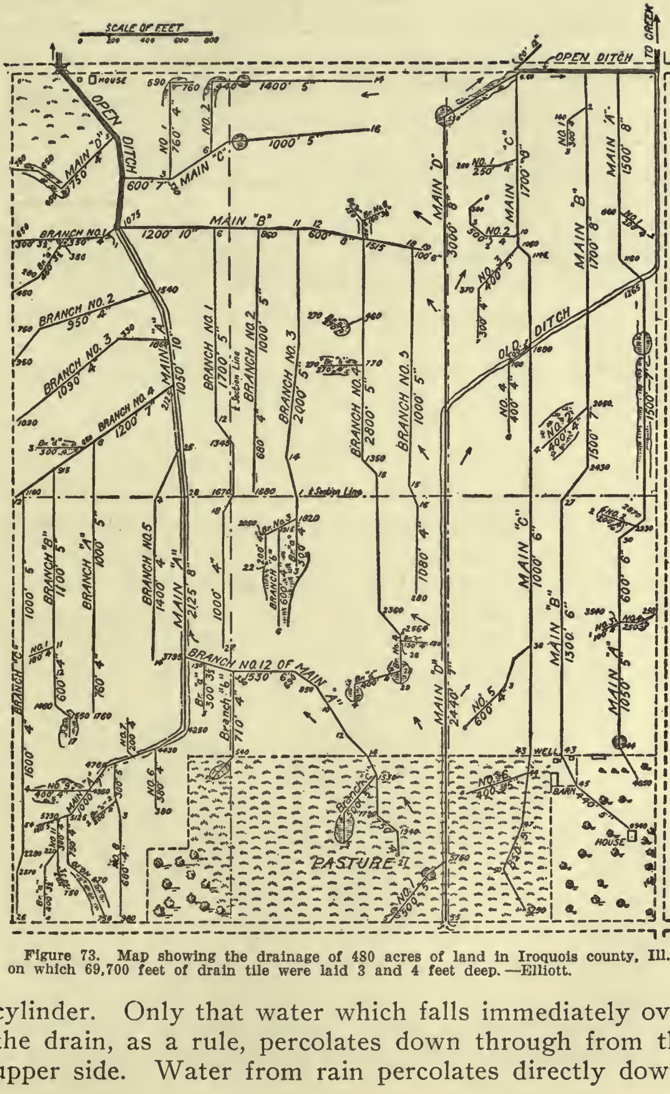

Figure 73. Map showing the drainage of 480 acres of land in Iroquois county, Ill., on which 69,700 feet of drain tile were laid 3 and 4 feet deep.—Elliott.

cylinder. Only that water which falls immediately over the drain, as a rule, percolates down through from the upper side. Water from rain percolates directly downward from the surface of the ground to the surface of the ground water, and then seeps sidewise into the

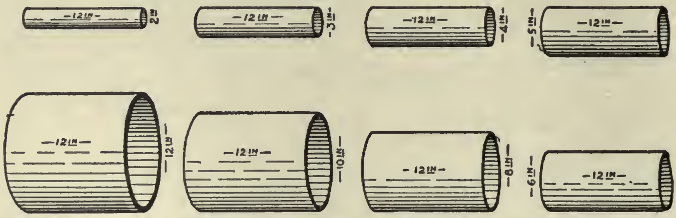

Figure 74. Common drain tiles.

stream running through the bottoms of the openings through the row of tiles. Since the ground water outside of the tiles is little higher than that inside, the seepage movement is nearly horizontal.

Survey for Construction

While the general inspection of the land referred to on a previous page might result in a choice of the approximate location of the main drain and its branches, it is necessary, on nearly level land, to attend to the details for the exact location of the line of the ditch. Where a slough or hollow with gentle slope is to be drained, it is often wise to supple-

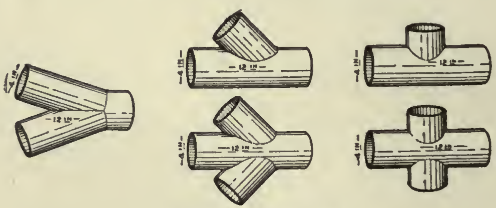

Figure 75. Union tiles.

ment the "bird's-eye" survey with a series of levels taken at intervals of 50 or 100 feet along the proposed line of the ditch. In some simple cases all that is necessary is to determine the height of the land at either end of the ditch and the depth of the ditch at these two points. Where the line is long and there is a variation in the slope of the surface of the ground, however, it is better to take a level at each stake placed every 50 to 100 feet alongside the line of the proposed drain. A line of levels

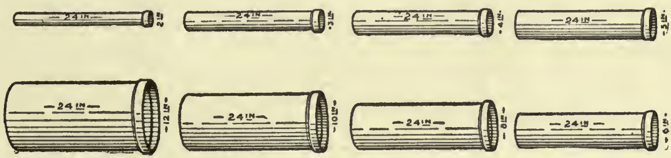

Figure 76. Collared drain tiles or sewer pipes.

thus taken and figured to express the height above datum, as will be explained later on, will serve as a basis for locating the exact line and depth of the proposed ditch. From the first line of stakes where the levels were taken, other levels may be taken at points on either side. A new line with slight or considerable deviation from the first line may be projected here or there, and by placing stakes along the new line and taking several levels, its practicability may be compared with the first location. In this way the best place for the main drain may be

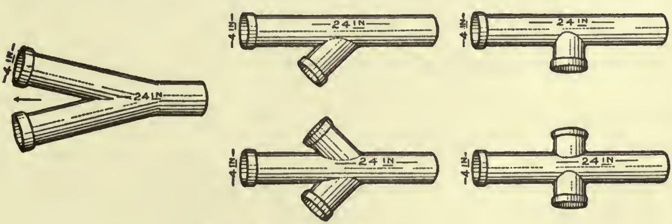

Figure 77. Branched collared tiles.

accurately determined in low areas where the problem is a comparatively simple one.

It is generally wise to have open ditches follow the lowest levels. This is especially true in the northern states, where snow and ice accumulate in open ditches, often clogging them when the surface water begins to run in the early spring. At the points where the open ditch passes through slight elevations of land, the snow accumulates by drifting and serves as a dam to prevent the early movement of water, whereas, if the drain follows the lowest level, even if the ditch is full of snow and ice, this soon melts or is worn away by the water from the higher surfaces which runs over it.

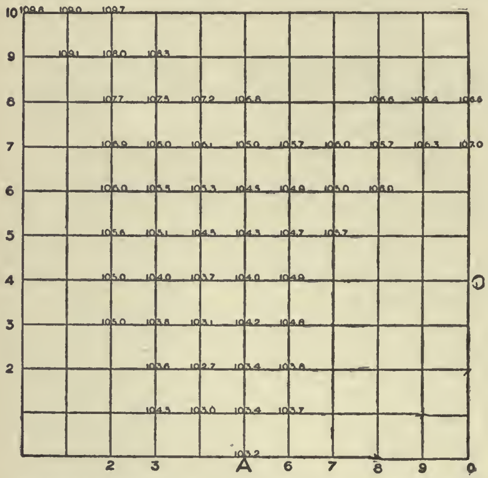

Figure 78. Elevations on a flat 40-acre field used in locating an open ditch and branch tile drains. The outlet of the open drain, which is 3.2 feet below the general surface at A, was taken as 100 feet above datum, and all figures show the elevation of the respective points above that datum plane.

A cross section or contour survey is sometimes necessary on a nearly level area. Figure 78 represents a 40-acre tract. Here, in a large area nearly level and difficult to drain, cross-sectioning was found necessary, that the main drain might be placed to the best advantage and that the least expensive method of laying lateral tile drains, to drain the low spots, might be devised. This level area is shown, with the levels taken every 132 feet each way.

To map out the drains, the contour map may be used to great advantage. In many cases, the drains can be laid out on this map by studying the map alone; in other cases it will be necessary to traverse the land with map in hand, and by inspecting both the map and the land, the drains may be placed in the most practicable positions. In some cases it will be necessary to accompany the general inspection of the map and land, with meas-

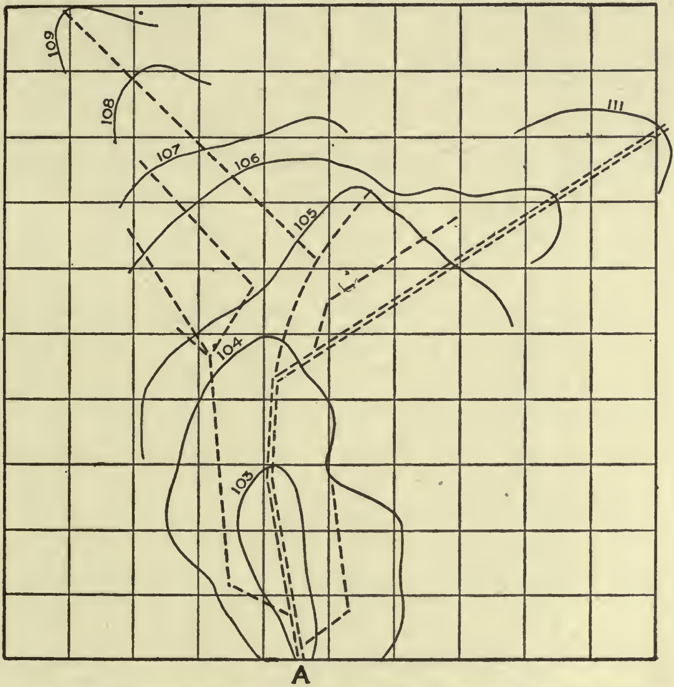

Figure 79. The curved contour lines, drawn through points of similar elevation, show the height of each part of the land above the outlet of the drain A. The slope of the land is at right angles to the contour line.

urements of the heights of points along the trial lines made by leveling instruments, and, where the expense is considerable, it will be wise to make profiles showing the amount of digging required in case of each of two or more ditches projected in the preliminary surveys. Since the whole system of drainage must be taken into consideration at one time, the main drain and the principal laterals cannot be fully decided upon, either as to

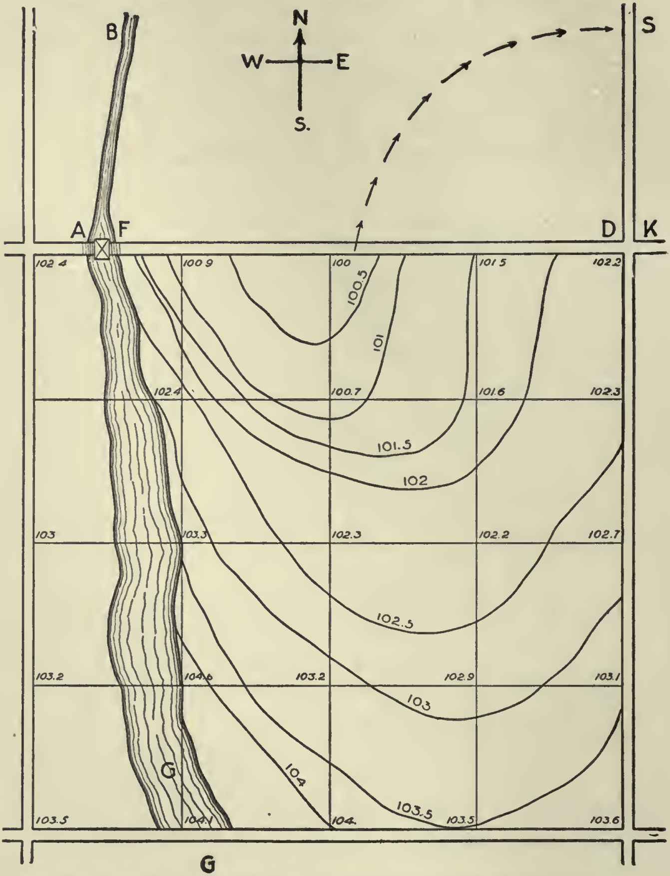

Figure 80. A "section," 640 acres, of level land drained by surface drains.

location or depth, until the laterals have been sufficiently measured or inspected to determine whether they will properly discharge water into their mains. In case of the tract of land shown in Figures 78 and 79, the flood water, coming through the northeast portion of the farm from farms beyond, necessitates the construction of a large open drain. Since water does not flow upon the tract from any other watershed of considerable extent, it seemed wise to make all other drains by the use of the tiles. Thus, while the slough entering the drain from the northwest, received some water from the farm beyond, it could best be drained by means of three lines of tile entering the open drain. The method of placing the drains in flat areas at either side of the open drains in the center of the farm illustrates how low areas may be reached with economy of labor and tiles.

Surface drains may sometimes be used to supplement tile drains, in countries where the ground freezes deeply. Thus, a broad, flat ditch thrown out with the reversible road machine, or even a dead furrow, will take the surface water from a low area before the ground is sufficiently thawed out to allow it to percolate downward to the under drain, and thus permit this low area to become dry as early in the spring as the surrounding areas.

A section of land with surface drains.—In Figure 80 is shown a section of land drained wholly by surface drains. This land is located in the Valley of the Red River of the North, some distance from a stream. Since there is a fall of only two to four feet per mile from this land to the river, it seemed impracticable to use tile drains until surface drainage was first thoroughly tried. Besides, this land is not often too wet except while frost is leaving the ground in the spring. This region being far north and the growing season short, it is necessary for the best results to get the crops into the ground as early in the spring as possible.

Figure 80 shows the general level character of this section of land. The drainage of this section for a practical farm illustrates numerous problems in the drainage of very flat, dense lands in a cold country. The slough or lake, F-G, in flood times, receives a large amount of water from the south which overflows its eastern banks, spreading out over the farm. With a large canal at A-B, this flood water will not overflow upon the farm. The figures giving the height of the several "forty" corners as compared with the lowest point at the middle of the north line, taken as a bench mark at 100 feet above datum plane, and the contour lines, dividing areas for each foot in height, show the direction of the very slight grades in the surface of this level farm. This land is very dense and water percolates slowly downward. Further, the level character of this land would necessitate tile drains being laid with such a slight grade that large-sized tiles would be required to carry off any considerable amount of water, and the cost of the tiles might be so great as to make their use impracticable, besides no outlet could be secured without carrying the main drain some distance to the river through lands belonging to other people. It is probable that this land would be materially benefited by tile drainage, and ways may be found of arranging the outlets for tile drains by extending and deepening the large canals being constructed to carry off the surface waters. Since surface drains could best be used in this instance, it was necessary to construct them so as to have them work rapidly and effectively very early in the season, and also be in repair to remove the excess of water at any time throughout the summer. This land being nearly level, the gentle slopes were easily determined when water was seen standing on parts of the land. In this case, cross-sectioning with the leveling instruments was hardly necessary, because the standing and the flowing water had shown the levels. That the reader may better appreciate the very level character of the main part of this section of land and other facts complicating its drainage, on the map have been placed cross-section notes representing levels at points 80 rods apart each way. The large slough shown, running through the section north by northwest, is really a long, narrow, shallow lake without outlet except over the nearly level land at the north end. To drain this, a large canal A-B, 16 feet wide and 8 to 10 feet deep, was necessary, and was constructed running from the north end of the lake a mile and a half across the nearly level country to a river. This canal, if made 10 feet deep, would be sufficient to drain the lake entirely, thus transforming it from a shallow lake, which, in a dry series of years, becomes entirely dry, into a hollow which could be plowed nearly to the center or could be used for meadow or pasture. Tile drains could then be laid, placing the main outlets in this large drain.

The surface drainage.—The water on the main part of the section may all be carried out in one of three ways.

The lowest point of this farm being at the middle of the north line of this section, at E, the flood water delivered at E could best be carried away from the farm by an open ditch, E-S, running northeast, following the natural depression across the neighboring farm, or could be carried through a rather deep ditch, E-A, westward to the canal at A, or it could be carried beyond the northeast corner of the farm through heavy road ditches and thence along the road either to the north or the east to the adjacent lower areas at S or K. If carried eastward, the water would flow into a new channel at K, and this might require the consent of the adjacent landowners. If carried northward, D to S, from the northeast corner of the farm, it could be emptied into the channel of the low area at S, which naturally would carry this water. If the discharge were made at the center across the adjacent farm toward S, a ditch running northeast across the neighbor's land would be necessary, and consent, on the part of the neighbor, to construct the ditch would be needed. This plan has the advantage in that there are no deep ditches to be clogged by ice and snow early in the spring. Carrying it westward along the road and discharging it into the canal seemed to be the most feasible plan. This, however, has proven to have the objection of not following the lowest levels, but requiring a rather deep, narrow ditch through a higher area, thus making a place in which the water is held back in early spring by the accumulated ice and snow. In most cases, a neighbor can be induced to agree to a ditch being made through a low area on his land, since it is advantageous to him to have his own land better drained and to have the flood waters from neighboring lands confined to definite channels, which rapidly carry them off. It would be economy for the owner of the farm to pay for the right of way of this ditch and construct it at his own expense, if this were necessary to secure the consent of the neighbor. On the other hand, its value to the neighbor should cause him to give free consent, and even to assist in making the ditch and in keeping it in repair. This illustrates the many cases where liberal co-operation of adjacent landowners is not only necessary to effect a good system of drainage, but is also right as between man and man.

Roadside ditches.—Having now decided upon the way of conducting the water from the lowest point at the middle of the north side of the section, we come to the problem of how best to conduct the surface water to this lowest point. This farm being a mile square, the public highway bounds it on all sides. By inspecting the cross section levels, as recorded in Figure 80, it will be seen that the land is highest near the shallow lake. This lake often became a stream which sometimes overflowed its banks. Doubtless the land adjacent to the lake was slightly built up from century to century by this flood water spreading out in the grass, where it rested so quietly as to deposit whatever solid particles the flood water had accumulated. This very slight increase of fine clay and silt, year after year, was probably sufficient to make this portion of the section a foot or two higher than the other portions.

It is interesting to know that in the level valley of the Red River of the North, and in the case of many other rivers, the land within half a mile of the rivers and streams is usually higher than the land some distance back, since these rivers frequently overflow; the cause mentioned in the previous paragraph seems to be the explanation. Consequently, there are large, wet, level areas found, from a half mile to several miles back from the Red River of the North and from the banks of the streams which flow into it through that level country. There are, occasionally, openings in these broad flat banks through which the flood water can run into the streams, but these are so few and the land is generally so nearly level that the drainage, on the whole, is often poor, and must be artificially improved much after the manner illustrated in the discussion of section of land mentioned in Figure 80.

In making a plan for surface drains, it was found necessary to begin on the south side of the farm, and instead of running the water toward the lake, now made into a stream or canal, to conduct it along farm ditches and public road ditches to the lowest point at the center of the north line, and from there carry it westward to the canal. Thus a large roadside ditch was provided around the south, east and north sides of the area to be drained. When more expense can be afforded, a deep ditch to carry the water westward along the south side of the section will be a valuable improvement.

By making broad ditches along roads dividing the farm into forty and eighty-acre fields, drainage water from this level land is discharged at points along the borders of the farm into these ditches. While the outside drains along the highway and the broad farm drains leading into them, of necessity, have very slight fall, the water can pass through them rather quickly, because they are broad and will hold a large volume of moving water. The drains inside the farm, conducting the water to these large roadside ditches, were placed so as best to conduct the water off the land, and they were located with reference to the arrangement of the fields into which it was decided to divide the farm. Thus, the north half of the section was divided into four 80-acre fields, and the southeast portion of the farm was divided into five 40-acre fields, with two triangular fields on the east border of the lake. The triangular portion on the west side of the lake was arranged for a single field and was drained in much the same manner as is described for the fields of the main portion of the farm.

The ditches between the several fields were made by means of the reversible road machine. Instead of making a ditch and throwing the earth out on either side, two flat ditches were made, throwing the earth to the center between them, just as in throwing up a grade for a road. This gave a place to deposit the earth, without placing it between the ditch and the level field to be drained. Since the very fine textured clay soils of this region are often drifted before the wind into the drains, this plan makes it practicable to clean the drains out occasionally with the road machine and provides a place to put the earth. If the area between the two ditches becomes too elevated or too much rounded, it is remedied by carrying the ditch farther out, thus making the rounded strip between the two ditches broader. The fence line can be placed on top of the roadlike bank, or, if there is no fence between the two fields, this can be used as a road over which to draw the loads of grain.

In case the two fields are planted with the same crop, it can be sown continuously through the ditches and over the flat embankment, or, if different crops are grown in adjacent fields, each crop may be planted to the center of the embankment. In many cases of level land, these side ditches may be made so broad that, even if more than a foot deep, since they are so flat, the plow and cultivating and harvesting implements may be operated across or through them. Care should always be taken, however, not to plow or cultivate in such a manner as to fill the ditches. On most nearly level farms these broad flat double ditches should follow the lowest places rather than as lines with which to divide the fields. Wire fences crossing them are easily removed, when it is desirable to use the reversible road machine to clean the accumulations of drifted soil out of the side ditches.

Dead furrows.—To conduct the water from the fields into these broad partition ditches, each field is laid off in lands about 100 feet wide. Each year the back furrows are started in the same place or within one or two feet of the same line, thus bringing the dead furrows, year after year, at the same place. These dead furrows are thus made into broad flat ditches. Where slight depressions occur some rods across and a foot or less deep, the road machine may be used to deepen the dead furrows, and thus grade their bottoms so that the water in these low areas will all drain out into the broad ditches between the fields. In some cases, it is necessary to make short broad ditches from low areas within the one-hundred-foot-wide lands into the dead furrows between. Care is necessary to keep the dead furrow clear of rubbish, and in some cases to open it out and grade its bottom smoothly in the fall. Where this opening of ditches has been neglected until spring, a man with a shovel connects the low places and shallow ditches with the dead furrows and cleans out the dead furrows to connect them with the larger ditches. In some cases the reversible road machine, or the slush or wheel scraper, should be used in these broad dead furrows to lower them through slightly higher places, thus making a uniform grade, that the water may run out better. By thus making a system of flat open drains and keeping them in repair, the farmer in the level lands of the Valley of the Red River of the North is sometimes able to plant his crops a week or two earlier in the season. He thus insures a better crop and gets his grain planting out of the way so that he may have the opportunity to plant his other crops in a seasonable time.

Surveying the line of the ditch.—Most drainage operations begin at the lower end of the ditch, the work proceeding upward, first along the main drain, then from the chosen points in the main drain where the branches are to have their junctions to the upper end of the respective branches. With the point and elevation of the outlet determined, a stake should be placed at points 50 or 100 feet apart along the line of the proposed drain. These stakes should be placed a foot from one side of the proposed ditch, that they may not be disturbed in excavating. Where the work must be very accurate, it is wise to use small stakes, 8 inches long and 2 inches square, for hubs. These are driven even with the surface of the land, beside the taller stakes which mark their position. See Figure 68.

The leveling instrument is then to be used in finding the relative height of the successive points marked by the stakes and hubs along the line of the proposed drain. Some point should be chosen for a bench mark. Any natural object which is not likely to be moved, as a large bowlder, or a stone firmly buried beside a post in a fence, will serve as such. The instrument should now be set up where the leveling rod can easily be seen when placed on the point chosen for the bench mark. See

Figure 58 and notes. For some purposes the long mason's level may be used, and levels may even be determined by setting stakes above the water level in a pond or lake. By having the tops of these stakes all extend the same distance above the water, a level line may be projected by sighting across their tops.

Use of the datum plane.—In comparing the height of the different points along the main drain and also along

Station No.	Back Sight	Height Instr't	Fore Sight	Elevation Ground	Fall of Drain	Elevation Drain	Depth Drain
B. M.	....	....	....	100.00	....	....	....
	5.32	105.32	....	....	....	....	....
0	....	....	9.43	95.89	Outlet	....	....
0	....	....	5.82	99.50	Surface	95.89	3.61
1	....	....	5.54	99.78	0.30	96.19	3.59
2	....	....	5.02	100.30	"	96.49	3.81
3	....	....	4.60	100.72	"	96.79	3.93
4	....	....	5.07	100.25	"	97.09	3.16
5	....	....	3.10	102.22	"	97.39	4.83
....	8.41	110.63	....	....	....	....	....
6	....	....	7.84	102.79	1.00	98.39	4.30
7	....	....	7.07	103.60	"	99.39	4.21
8	....	....	6.43	104.20	"	100.39	3.81
9	....	....	5.63	105.00	"	101.39	3.61
10	....	....	5.23	105.40	"	102.39	3.01
11	....	....	4.38	106.25	"	103.39	2.86
12	....	....	3.93	106.70	"	103.79	2.91
13	....	....	3.39	107.24	"	104.19	3.05
....	6.06	113.30	....	....	....	....	....
14	....	....	5.30	108.00	.40	104.59	3.41
15	....	....	5.00	108.30	....	104.99	3.31
16	....	....	4.70	108.60	....	105.39	3.21
17	....	....	4.05	109.25	....	105.79	3.46
18	....	....	3.90	109.40	....	106.19	3.21
19	....	....	3.57	109.75	....	106.59	3.14
20	....	....	3.13	110.17	....	106.99	3.18

Fig. 81. Blank form used in recording notes of levels taken while planning for a drain.

its branches, some method is necessary by which the relative heights of all these points may be ascertained. There are several ways of doing this, but what is wanted is a simple plan of calculation which will be accurate and will clearly show the relative height of points with each other and especially with the outlet. The following plan is in common use, and with practice can be employed to good advantage. After having carefully leveled up the telescope of the instrument, direct it to the measuring rod standing on the point chosen for a bench mark near the outlet of the proposed drain; indicate to the rodman who is holding this rod, to move the disk up or down until its center is in line with the eye and the horizontal cross hair in the telescope. The rodman should then read on the measuring rod the exact distance from the bench mark up to the center of the disk and record same in field notes, as in Figure 81. This gives the height of the instrument above the bench

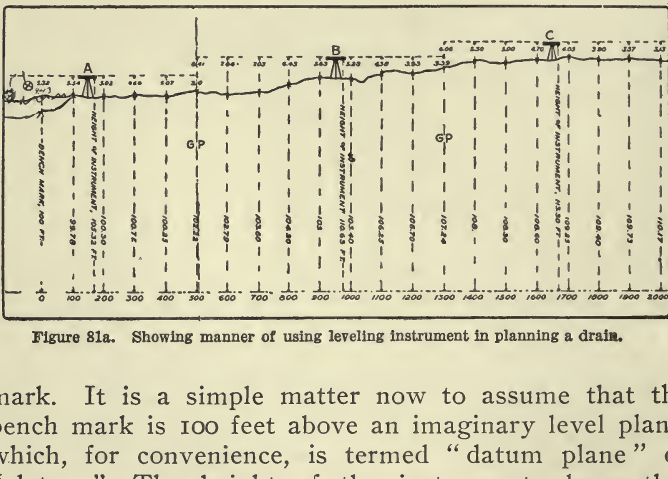

Figure 81a. Showing manner of using leveling instrument in planning a drain.

mark. It is a simple matter now to assume that the bench mark is 100 feet above an imaginary level plane, which, for convenience, is termed "datum plane" or "datum." The height of the instrument above this imaginary plane is 100 feet plus the distance above the bench mark to the disk on the measuring rod, which is level with the eye at the instrument. To make the illustration more complete, we will assume that the reading in a given case on the measuring rod was 5.32 feet. Adding this figure to the height of the bench mark above datum, i. e., to 100 feet, we have the height of the instrument above datum—105.32 feet.

In some cases it is more convenient to find the height of the instrument in its first position above the point determined upon for the outlet of the proposed drain, and then assume the datum plane 100 feet below the outlet. Then all figures showing elevation of points on the surface or the bottom of drains may be compared with the outlet by merely subtracting the 100, which can be done by inspection, saving calculation with pencil.

Now, turning the telescope toward the proposed point of outlet for the drain, where the rodman will place the measuring rod, the disk is again moved until it is in line with the eye and the cross hair in the leveling instrument. We find that the reading on the rod now is 9.43 feet. To find the height of this point of outlet above "datum," we have only to subtract this reading from the height of the eye at the instrument called "height of instrument" above datum, thus 9.43 feet from 105.32 feet equals 95.89 feet; that is, the outlet of the drain is to be 95.89 feet above the imaginary level plane. Next a measurement is taken on the surface of the ground immediately above the outlet, which may be called Station 0, and this is found to be 5.82 below the instrument, or 99.50 above the datum plane. These measurements and the calculations from them are all placed in the note book ruled in the form for field notes, as in Figure 81. This form makes it practicable to carry forward all the calculations and to make a permanent record as the taking of levels proceeds.

Now, proceeding to the next stake, Station 1, there being 100 feet between the stakes, the reading is taken in like manner, and it is found that from the instrument down to the hub at the surface of the soil is 5.54 feet; subtracting this measurement from the height of the instrument, 105.32 feet, we find the height of the ground at Station 1 to be 99.78 feet above datum. The instrument is next turned upon the third stake, which is Station 2, and the reading shows 5.02 and by subtracting we have 105.32 feet, minus 5.02 equals 100.30 feet as the height of Station 2 above the imaginary plan called datum. Again, proceeding to Station 3, the rodman holding the measuring rod reports that the disk has been stopped in line with the telescope at 4.60 feet. This measurement, subtracted from the height of the instrument, shows that Station 3 is 100.72 feet above datum. Station 4 shows that the line is 5.07 feet below the instrument, or 100.25 feet above datum. Station 5 is found to be 3.10 feet below the instrument, or 102.22 feet above datum.

Getting the new height of the instrument.—As a matter of convenience or of necessity, to see the disk on the measuring rod at a long distance, the instrument is moved forward so as to be nearer the successive points along the line of the proposed drain, the heights of which are to be determined. The operator proceeds several stakes beyond the rodman, who remains at the last stake, the height of which was last measured. When the instrument is again set up, it is turned upon the measuring rod standing on the hub, the height of which was last determined with the instrument in its previous position. The rodman moves the disk until in line with the instrument in its new position. He then finds that the measurement is 8.41 feet. The instrument is now considerably higher than in its original position. Since the hub on which this measuring rod is standing is known to be 102.22 feet above the imaginary level datum plane, and the eye at the instrument is on a level 8.41 feet above the hub, the height of the instrument is now 102.22, plus 8.41, or 110.63 feet above datum. With this new height of instrument, it is now practicable to proceed to Station 6 and determine its height above datum. Here the rodman, after moving the disk until told that it is level with the instrument, reports that the stake is 7.84 feet below the point where the disk has been placed level with the instrument, which is 110.63 feet above datum; Station 6 is then 110.63 feet, minus 7.84 feet, or 102.79 feet above datum. In like manner, the height of Stations 7, 8, etc., are successively measured; or when the earth at the stations is higher than the level of the instrument, the operator must again move the instrument, and, sighting back (getting the "back sight") to the point last measured, again find the new height of his instrument. In this manner we proceed to Station 20; that is, 2,000 feet from the outlet.

That we may now illustrate the method of getting the new height of the instrument when going down grade, and, where necessary for great accuracy of checking up the work already done, we will begin at the upper end and check the levels at the successive stations back to the proposed outlet. By referring to Figure 81 it will be seen that the elevation of the surface at Station 20 is 110.17 feet; and that the instrument standing in its last position is 3.13 feet above the hub at this point, or is 113.30 feet above datum. Now, turning again on Station 19, the rodman reads 3.57 feet, and subtracting this from the height of the instrument above datum, we have as the height of Station 19, 109.73 feet. Proceeding to Station 18, the rodman reads 3,90 feet; at 17, 4.05 feet; at 16, 4.70 feet; at 15, 5 feet; at 14, 5.30 feet. On account of the distance, it is now deemed advisable to get a new height of instrument, and the instrument is moved down to the neighborhood of Station 9. When the instrument is properly leveled up and turned on Station 14, the rodman finds his disk in line with the instrument at 2.47 feet. Since the height of the surface at Station 14 is 108 feet and the instrument is found to be 2.40 feet higher than at this point, the new height of the instrument is calculated to be 110.40 feet.

When directed to Station 13 the rodman reports the measurement from the instrument down to the hub as 3.16 feet, making the elevation of Station 13, 107 feet. So far the measurements have proven the original survey correct, since upon taking the measurements from the level of the instrument down to the several stakes, their respective heights above datum figure out the same as when measured up grade. By thus proceeding downward to the outlet, changing the instrument once more, if there is but little variation found in any of the measurements the first survey is proven accurate, and when the height of datum is measured, it is found to

Station No.	Back Sight	Height Instr't	Fore Sight	Elevation Ground	Fall of Drain	Depth Drain
B. M.	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	113.30	....	....	....	....
20	....	....	3.13	110.17	....	....
19	....	....	3.57	109.73	....	....
18	....	....	3.90	....	....	....
17	....	....	4.05	....	....	....
16	....	....	4.70	....	....	....
15	....	....	5.00	....	....	....
14	....	....	5.30	108.00	....	....
13	110.40	2.47	3.16	107.24	....	....
12	....	....	....	....	....	....
11	....	....	....	....	....	....
10	....	....	....	....	....	....
9	....	....	....	....	....	....
8	....	....	....	....	....	....

Fig. 82. Same as Fig. 81, with measurements of levels taken down grade.

be 99.99 feet above datum plane or practically correct. See Figure 82. By testing the adjustment of the instrument before starting out and doing the work accurately, the experienced man can usually depend upon his levels. But if a great difference is found between the two surveys, the measurements should be again made with accuracy, and, if still an error appears, the instrument should be tested and, if needing adjustment, a competent person should be employed to repair and adjust it.

"Back sight" and "fore sight" or "plus sight" and "minus sight."—In the tabulated statement, Figures 81 and 82, the measurements from points of known heights up to the instrument are called back sights, or sometimes plus sights; that is, we add the height from the surface up to the line of sight through the instrument to the known distance above datum of the surface where the leveling rod stands in order to get the new height of the instrument.

There is a column in the table headed fore sight, sometimes called minus sight. In this column are placed the measurements from the height of the instrument down to given stations, the height of which it is desired to know. Since the instrument is always higher than the point we wish to measure, we always subtract the measurement from the height of the instrument down to the point in question so as to determine the height of that point above datum. These measurements, which are to find the height of the surface of the ground, are properly termed minus sights, to be subtracted from the height of the instrument, as distinguished from the plus sights, which are added to the known heights of given points, which are always used to find the height of the instrument. Back sights are often abbreviated B. S. and fore sights F. S., in the tabulated notes.

How to use measurements of levels.—Now that the levels of the successive stations along the proposed line of the ditch have been determined, a method of using them is necessary. Where there is considerable fall, very little surveying or calculation is needed since an experienced person can determine the depth the ditch should be at each station by merely inspecting the figures and the land. In cases, however, where the proposed drain is long, where the grade is slight, or where slight elevations requiring deep ditches necessitate considerable expense, or where the connection of lateral drains with a drainage system complicates the problem, it is sometimes wise to use profile paper in making what is termed a profile of each of the proposed ditches.

The profile is a great help in devising the proper grades for long drains on very flat areas so as to have them sufficiently deep in the lower places, not too deep where the digging would be considerable and yet have the most practical grades for effectually carrying off the water at the least expense for construction.

How to make a profile.—The figures representing the height of the successive stations above datum, as recorded in Figure 81, are used to show the surface of the

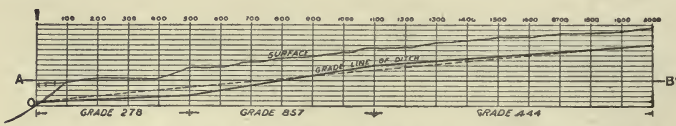

Figure 83. Profile showing surface and the grade line of the ditch, thus giving the depth of the ditch.

land at each station. Figure 83 shows how the heights above datum are mapped into a profile to show the surface of the earth along the line of the ditch, from its outlet to its head. This line having been mapped in, another line beneath the surface can be drawn, showing the bottom of the ditch, whether tile drain or open ditch. By careful inspection and measurement, or by counting the lines, this line representing the grade of the ditch can be so placed that the ditch will not be made unnecessarily deep and expensive, nor yet too near the surface at any point. It will be observed that points have been chosen along the line of the ditch where the grade is slightly changed. Between these points straight lines are drawn, showing that the grade is to be uniform between the chosen points. By using a soft pencil, these points for changing the grade may be located and trial lines made, and, if not in the right place, they may be erased and other trials made, until the depth of the proposed ditch at the various points is so arranged as to make an effective system of drains without unnecessary expense.

In case of branch drains, it is sometimes necessary to make profiles of the several branches before finally deciding upon the grade and depth of the main drain, showing their relations to the main drain, in order that the entire plan of the drainage system may be so mapped out as to make all parts fit together in a manner that will insure practical slants, or grades, for carrying the water from all portions of the land, and yet will not necessitate deeper and more expensive drains than necessary.

The profile in Figure 83 shows the surface line of the ground at each station on the line of a proposed ditch, as determined by the use of the level, the leveling rod and the calculations, Figure 81. This profile is so made that the vertical lines represent the stations 100 feet apart, O representing the outlet. Each horizontal line represents a foot in height. The horizontal line A-B represents a line 100 feet above datum. It may be seen from this profile that between Stations O-5, 5-11 and 11-20 the profile of the ground surface presents three different grades. While it would be possible to give the ditch a uniform grade between Stations O and 20, as indicated by the dotted line, it would be impracticable, as it would bring the ditch too near the surface between Stations 1-6 and too deep between Stations 10-16. To avoid this the ditch is run on three separate grades, which give it a nearly uniform depth and still allow sufficient slope to carry off the water.

By deciding upon the depth of the drain at each point chosen for a change of grade, the amount of fall per 100 feet can be determined between each of two points of change. Then, by subtracting the depth of the ditch at each point of change of grade from the elevation of the surface of the ground above datum, the elevation, above datum, of the bottom for the ditch at these points can be placed in the column for Elevation of Drain. The difference in the elevation of the drain above datum between two points divided by the number of stations 100 feet apart gives the grade per 100 feet. By beginning at the lower point and adding this amount to the height of each station, the height of the next station is determined. The depth of drain at each station is then determined by subtracting the height of the drain above datum from the height of the surface of the ground above datum at that station. These records can be copied from the notebook upon stakes and thus show the depth to dig the ditch at the respective stations.

Deciding upon amount of slope or grade.—In deciding the most practical grade, or slant, of the line of the drain, and the size of the ditch or the diameter of the drain tile, rules are of some use, but very often these matters can best be determined by one who has had practical experience under similar conditions. In rare cases, a steep grade causes an open ditch to be gullied out by the swift running water, and a more level grade with an occasional waterfall buttressed with stones would be better, but generally on flat lands the effort should be to secure a rapid fall in the grade. In some cases, for example, in the Valley of the Red River of the North, in Holland, and in other very flat countries, large open drains must, of necessity, be made nearly level. It is astonishing how much water will be removed by an open drain that has only a few feet of fall per mile, or a tile drain that has only 2 to 4 inches fall per 100 feet. Width of the ditch, or diameter of drain tile must largely make up for lack of fall, since water that has so little speed must be carried in a larger drain

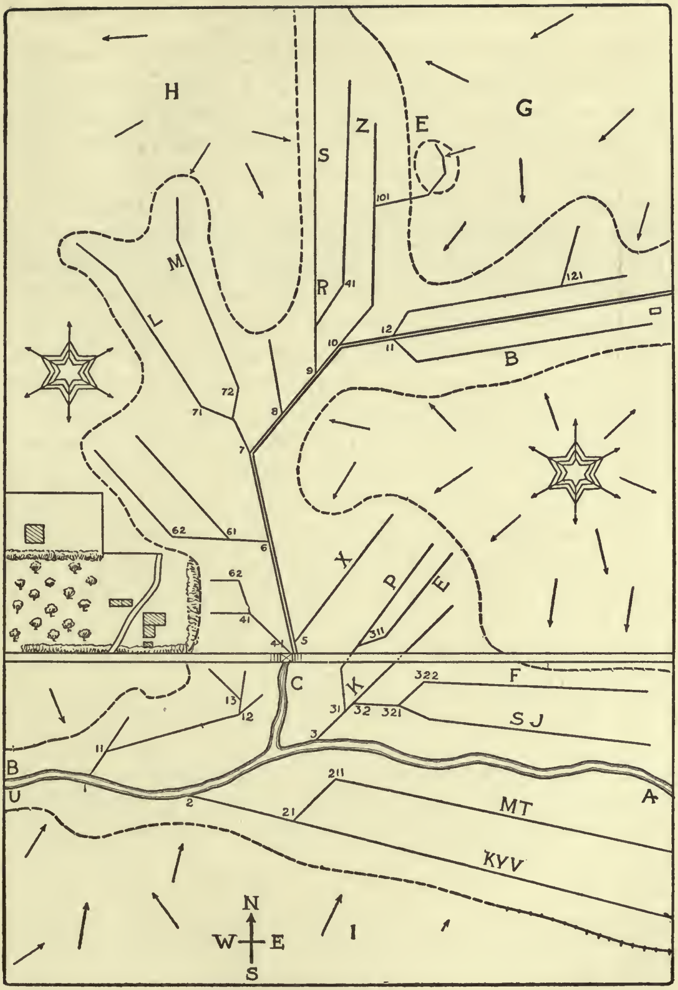

Figure 84. Showing system of mapping drains and sizes of tiles in low places on a 240-acre farm. The double curved line south of the highway is a creek; the double line on the north of the highway is an open ditch. The tile drains open into the creek and open ditches. The rainfall is about 30 inches, and except in line of the open ditch no large amount of flood water need be provided for. (See notes at bottom of page 196.)

in order to remove the volume of flood water or rainfall. The minimum grade for tile drains is usually considered as about 2 inches to the 100 feet. Generally, tiles need not be laid at a less grade than 4 to 6 inches fall to the 100 feet.

The size of tiles to be used is important, because drains which are too small to carry a given amount of water at a given grade will not drain off the water rapidly enough to avoid injuring the crops, and the use of tiles larger than necessary is a waste of money. The amount of rain which annually falls in a locality, the flood water received by the wet area from surrounding lands, the distance apart of the drains, the presence or absence of seepage or spring water in the subsoil, the character of the subsoil, the amount of fall, or grade, given the drain, and sometimes other considerations, make the problem a complicated one. In the notes under Figure 84, the sizes of tiles to be used in the various main and branch drains there mapped are specified, together with the

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Main 1, from 1 to 12, has a grade of 4 inches per 100 feet; and 4-inch tiles are used from 1 to 11, and from 10 to 12, also from 12 to 13. Branches 11, 12 and 13 have grades of 4 inches per 100 feet, and 3-inch tiles are used.

Main 2 and its branches are all laid at a grade of 8 inches per 100 feet. A 6-inch tile is used from 2 to 21, 5-inch from 21 to 211, 4-inch tiles from 21 to K, and 211 to M, and 3-inch tiles thence to the upper ends of the two branch drains.

Main 3 has a 6-inch grade to K, thence 10 inches. Sizes tiles used: 6-inch, 3 to 32, and 3-inch beyond K. Branch 32 and sub-branch 321 have a grade of 8 inches, and 322 a grade of 8 inches to F, and 12 inches from F to the upper end. Sizes used: 5-inch on 32 to 321, 4-inch on 321 to S and 322 to F; 3-inch above F and S. Branch 31 and sub-branch 311 have a grade of 6-inch to P and E and beyond 10 inches or more. Sizes used: 4-inch, 31 to 311; beyond, 3-inch.

Main 4 and its branches, 8-inch grade; 4-inch tile 4 to 41, and beyond 3-inch tiles.

Main 5: Grade 5 to X, 3 inches, 5-inch tile; grade X to upper end (springy hill-side). 10 inches, 4-inch tile.

Main 6: Grade 6 to 62, 10 inches, tiles 4-inch; grade branches 61 and 62, 8 inches, tiles 3-inch.

Main 7: Grade 10 inches, tile 5-inch; branch 71, grade to L, 6 inches, and beyond 12 inches or more; tiles 4-inch from 71 to L, and beyond L 3-inch; branch 72, grade to M. 8 inches, and beyond 10; tiles 4-inch from 72 to M, and 3-inch beyond.

Main 8: Grade, 16 inches; size, 3-inch.

Main 9:. Grade to R, 10 inches; tile, 5-inch; grade R to S, 6 inches, tile, 4-inch; grade beyond S, 12 inches; tile, 3-inch; branch 91, grade, 8 inches; tile, 91 to C, 4-inch; C to upper end, 3-inch.

Main 10: Grade 10 to 101, 10 inches; beyond, 14 inches; branch 101, grade, 36 inches or more (the upper end tapping a spring with considerable water); tiles, 10 to 101, 8-inch, beyond 3-inch; tiles, 101 to F, 6-inch, beyond 4-inch.

Main 11: Grade to B, 18 inches, beyond B 20 inches; tiles, 11 to B, 4-inch, beyond B 3-inch.

Main 12: Grade 12 to 121, 20 inches, beyond 121, 24 inches; tiles 12 to 121, 4-inch; beyond 122, 3-inch; branch 121, grade 36 inches; tile, 3-inch.

length and grade, showing how maps and specifications can be made.

Depth to make drains.—The roots of nearly all cultivated plants grow best where the surface of the ground

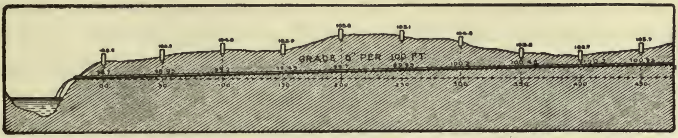


Figure 85. Showing elevation of the soil above datum, also elevation of drain at stations 50 feet apart, as entered from surveyor's blank.

water is at the depth of 3 to 6 feet or more, so that they can spread in soil containing only capillary water with the interspaces filled with air down to at least some feet. Tile drains may be laid 3 or 4 feet deep rather cheaply, but deeper than this the expense increases rapidly. Extensive experience has led farmers to lay tile drains at the depth of 3 or 4 feet where there are no special reasons for laying shallower or deeper. In some cases where the water percolates through soils very slowly, it is best to lay the tiles not deeper than an average of 2 feet. Since the drain must have a nearly uniform fall

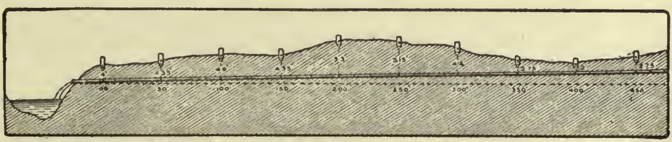


Figure 86. Depth of ditch at each station, secured by subtracting height of ditch from height of surface on surveyor's blank.

regardless of the contour of the surface of the ground, and at all points must slope toward the outlet, the drain is necessarily deeper at some points than at others. In low places, it is sometimes necessary to bring the tiles nearer the surface; always, however, keeping them sufficiently deep that they will not be disturbed by the plow.

Where deep subsoiling is practiced the top of the tiles should be at least 15 inches deep, and, in no case, even in rather open soil, which will not need subsoiling, should the tiles be laid nearer the surface than 10 to 12 inches. In case of very dense subsoils, where fine, dense clay is thrown back into the ditch over the deeply laid tiles, the surface water may be prevented from reaching the drain quickly, especially if it be laid too deeply, and the drain be, therefore, of little service. If the ditch be filled with gravel or other porous material, the water

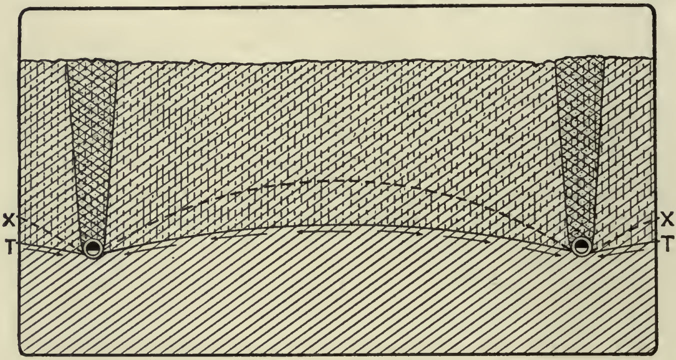


Figure 87. Cross section through two tile drains showing direction the water follows in reaching the openings in the tiles. After a heavy rainfall the surface of the ground water rises to the line X. As this gradually seeps sidewise into the bottoms of the tiles the surface of the water sinks, as to the line T.

can get into the deep drain quite as readily as if it were nearer the surface. This precaution is necessary only in rare cases.

Special survey notes.—In surveying out the line of the ditch, special notes should be made of all unusual features, and of the exact points at which laterals branch off, and, where practicable, the location of the drain at different points, as where crossing a line of land survey, or near a monument which has been recorded in previous land surveys; these should be carefully noted, showing the exact distances and directions to given points, so that the under drain may be easily located at any time.

Notes on grade stakes.—In making careful surveys with grade stakes every 50 or 100 feet, the depth to which the ditch is to be dug at these points should be marked on the stakes. Thus, in Figure 86 are shown stakes; at the first stake the cut is to be 4 feet; at the next stake it is to be 4.35 feet, etc.

Surveyor's notes should be preserved.—Where the drainage problem is sufficiently complicated and difficult to require a careful survey, the notes should be systematically recorded and drawings and profiles should be so made as to make a permanent record of the survey and of the finished drain.

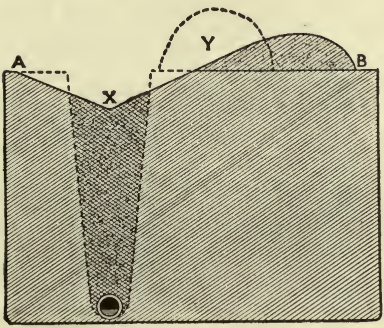


Figure 88. Earth removed from A X to B with reversible road machine; from X to Y with spade.

The plat of the land should show the general land survey.—In cases of large drainage enterprises, a copy of the government land survey may be made, and to this the surveyor's notes added, making such contour maps as are necessary, and locating the lines of the main and lateral open and tile drains. A system of naming or numbering the main and laterals, such, for example, as is carried out in Figure 84, should be adopted. The daily notes in platting and leveling can be taken in a notebook and should be at once transcribed upon the map upon which the drain is to be platted. Simple drawings made on pages of the notebook will aid in keeping a record of the linear measurements and angles while making the general land survey and the leveling measurements, also in making the profile. The profiles of the main and of each lateral drain should show all elevations, grade lines and bridges; and, in case of tile drains, any special features, as silt wells, etc., should be given.

THE CONSTRUCTION OF TILE DRAINS

Much effort has been expended in the construction of machines for making underground drains which open out the ditches and, at the same operation, lay the tiles and return the earth into the ditch. While some substantial progress has been made with this class of machinery, it is at best adapted only to long lines of ditch to be made in land free from stones. The man with the spade must continue to make the tile drains in all difficult places and in cases where the line of the drain is not sufficiently long to warrant the use of machinery.

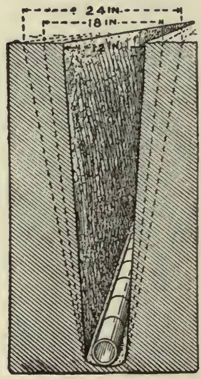


Figure 89 represents a ditch opened up 12 inches wide at the top, 6 inches wide at the bottom, 4 feet deep, and adapted to 4-inch tiles. Making it 18 inches wide at the top, adds one-third to the amount of earth handled; and making it 2 feet wide at the top adds two-thirds to the earth handled.

Opening with spade.—Like the survey, as a rule, the work should begin at the lower end or outlet of the drain. In some cases, the upper 8 to 12 inches of earth may be easily thrown out by means of a common plow or the reversible road machine. To make the line of the ditch straight, a cord may be used to mark one side of the ditch. Those who have not had experience will be surprised that the ditch should not be more than 10 to 12 inches wide at the top for a ditch 3 or 4 feet deep. Figure 89, with notes, illustrates the fact that much less earth is handled in the narrow ditch. Experience will convince anyone that there is no serious inconvenience in working in a narrow ditch. In fact, the sides being perpendicular and near together, is an advantage in enabling the spademan to work loose his spadefuls of earth.

Figure 87 shows the movements of rainwater in its course into the tile drain. The curved line, T-T, represents the surface of the zone of ground water. Above this, the rainwater is represented by the dotted lines as percolating directly downward. When it reaches the surface of the standing water and adds to its height, the ground water flows faster sidewise toward the tiles, which are so laid as to allow it to flow between their ends and flow away through the tiles, and thus prevent the ground water rising higher and smothering the roots of the plants. In case of a very heavy fall of rain, the ground water accumulates more rapidly than it can seep sidewise to the tiles, or possibly is in such quantity that the tile cannot carry it all off, even though running full. The line X shows how the water rises between tiles laid at intervals of several rods apart. The position of the lower curved line and the water within the tiles illustrates the fact that the water passes into the lower half of the tile and that it can seep in through the openings between the ends of the tiles, not needing to pass through the walls.

Figure 90. Tile or ditching spade, blades made 18, 20 and 22 inches long, 6 to 7 inches wide, and much curved, as shown in cross section at A. This is a surprisingly useful tool in opening tile or open drains in many easily worked soils. By turning it at an angle as shown in Figure 93 the bottom of the ditch may be made as narrow as desired for a 3 or 4-inch tile.

Figure 91. Small tile spade, blade 17 inches long, 4½ inches wide at top, used in bottom of narrow ditch for 2 or 3-inch tiles. Not much used, as the ditching spade, Figure 90, handles the earth better.

In Figure 93, A shows the manner of sinking the spade in taking out the successive courses in opening a tile drain by hand in a free soil. B, C, D, E and F represent succeeding courses. By thus "racking" the spade, each block of earth is broken loose from the side, leaving a square, even bank. Since only one side is broken loose and that with a revolving motion, it is removed with a small expenditure of force. Being broken loose so easily, it is not so much crumbled up and the spademan gets out nearly all he has broken loose. The succeeding courses are removed in a similar manner. In case of lower courses, D and E, Figure 94, if the ditch is narrow, there is economy of labor in using a spade with a long, narrow blade, taking a deep thin slice or block from the edge of the course, cut diagonally by each previous use of the spade. While apparently a small matter, a trial of this idea will illustrate the wisdom of constantly exercising intelligence in finding easy ways of doing the plain, hard work of the farm.

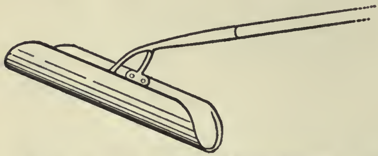


Figure 92. Tile hoe for grading bottom of tile ditch.

In Figure 94, the man A is cutting the sod at either side line of the ditch. B, C, D and E are spading out successive courses of earth, F is grading the bottom of the ditch to a true uniform slant, using the grading staff, H, to keep the bottom of the ditch parallel with the steel wire stretched at the desired slant at a given distance above the grade. The arm on the grading staff is adjustable to whatever distance the steel wire is placed above the bottom desired for the ditch. I is laying tiles by hand in the bottom of the ditch. At J a branch drain enters the main drain. K is laying tiles with a tile hook, as on a bottom too soft to bear a man's weight. L is filling in several inches of earth over the tiles, tramping it compactly over them. M is filling in the bulk of the earth with a shovel.

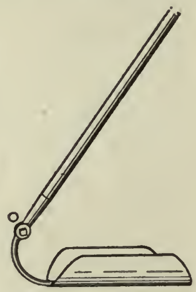


Figure 92a. Tile hoe, adjustable to push or pull.

Grading the bottom of the ditch.—Making the bottom of the ditch uniform in grade, or fall, toward the outlet is the only difficult part of constructing a tile drain. Where water gently oozes out into the ditch from the surrounding soil and runs toward the outlet, it can be used by the experienced man as a guide in grading the bottom of the ditch. The eye soon learns to judge by the rippling of the water in the bottom of the ditch whether or not the grade is uniform. If the stream lies smooth and sluggish in one place and flows rapidly in another, the tile hoe is used to make the ditch deeper at the upper portions of the rapids, and thus the grade is made so even that the water runs with a uniform speed throughout the entire length of that part of the drain which is being constructed on a given grade. Where the grade changes, as in changing the grade below a given station to another grade above, the eye must be trained to adjust the new grade to the flow of water. If the depth of the ditch at the separate stations has been placed on stakes, by measuring down when the new station is reached the grade can be corrected, as each stake is approached, so as to keep it at that depth

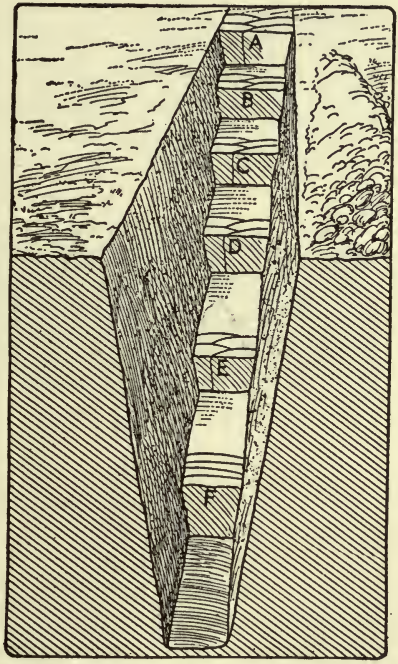


Fig. 93. Method of spading out successive courses in opening a ditch for tiles.

decided upon in working out the survey notes. In grading with water, the safest way is to go too shallow rather than too deep, as it is not always practicable to fill in with loose materials under the tiles in running water. This can, of course, be done by using gravel or coarse stones which will not be displaced by running water. Many practical ditchers require no survey whatever if there is water in the ditch, and ample fall, since they

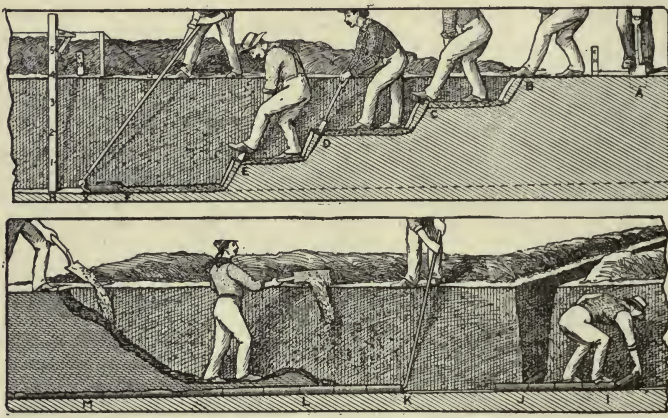


Figure 94. Ten men performing successive operations in opening the ditch, grading the bottom and filling the ditch.

can lay out the general plan of a drain with the eye, and by carefully using the water as an indicator can make a thoroughly practical drain.

The triangular tile drain grader, shown in Figure 95, may be made any suitable length, as 10, 12 or 16½ feet. When the lower board is level, a large nail is driven in its upper edge immediately under the point of the plumb bob. If it is a rod long, it may be adjusted to grading 2, 4, 6, 8, 10, 12, etc., inches per 100 feet by using blocks one-third of an inch thick under one end, driving a nail under the point of the plumb bob each time the upper end is raised by the addition of one of these blocks, just as the device shown in Figure 96 is adjusted to similar changes in grade by moving the bolt supporting the upper board into holes one-third of an inch lower. If the device is shorter than 16½ feet, the size of the blocks used in placing the nails should be proportionately thinner. Thus, if 10 feet long, the blocks should be one-fifth of an inch thick. Figure 96 illustrates a grading frame used in leveling ditches. A, spirit level; B, hinged end of board at back or lower end of frame; C, loose end of board at front of frame, which can be lowered or raised, so that, when the spirit level stands level, the bottom board, D to E, will have the desired slant to give the bottom of the ditch the proper grade. The frame is pulled forward as fast as the ditch is lowered sufficiently to allow of its being moved without throwing the spirit bulb out of level. A change for a steeper grade is made by putting the pin at C in a lower hole, and to a slighter grade by putting the pin in a higher hole.

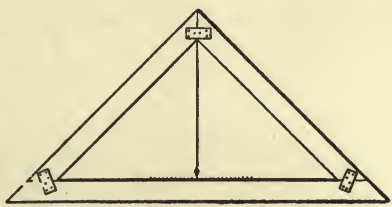


Figure 95. Triangular tile drain grader.

Grading devices.—In Figures 95, 96, 97 and 98 are shown different forms of leveling devices found useful in making the bottom of the tile drain at a uniform grade. Proceeding from one station to another, the accuracy of the grading frame is tested by measuring down from the stake at the new station. If the grade has been too great, and the ditch is not sufficiently deep, the grading frame should be readjusted to a slightly less grade, and if the ditch is too deep when the forward station is reached, the frame should be readjusted to a greater slant.

A small steel wire, such as is used in wrapping brooms, stretched from station to station, 50, or even 100, or more, feet apart, and placed at a given distance above the desired grade, serves as a line from which to measure down to the bottom of the ditch. The ends of the wire can be placed at the same distance above the desired grade and parallel to it. The depth for the ditch at each point being known, the wire can be attached to each stake high enough to make the wire a given distance above the desired bottom of the ditch, say 7 feet. It will be convenient to have it high enough to be out of the way of throwing out the spadeful of earth. To find the proper depth to make the ditch, an L-shaped meas-

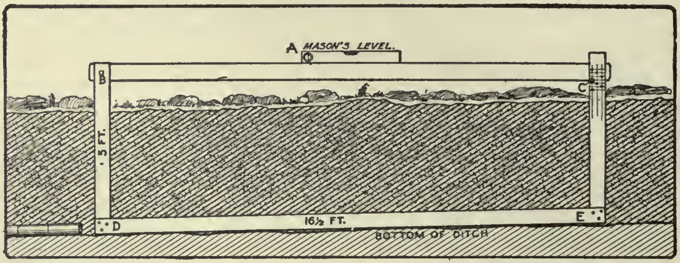


Figure 96. Grading frame used in leveling the bottom of tile ditches.

uring rod may be used to measure down from the wire, which may be placed at one side. By using stakes, as in Figure 101, the wire can be stretched so tightly that it will not sag.

Laying tiles in the ditch.—Where the material in the bottom of the ditch is not too soft, laying by hand, as shown at I, Figure 94, is the better way of placing the tiles in position. When placed by hand the tiles can be so turned and adjusted that the ends will be sufficiently close together to prevent earth falling in between. Where material under the bottom of the ditch is so soft that treading on the tiles displaces them, it is necessary to lay the tiles with the tile hook, as shown at K, Figure 94. By exercising a little dexterity, the tiles can be placed, and even revolved on the hook, so as to make the unions fairly tight. There is rarely danger of having the ends too close together, as a very narrow opening will allow the water to enter. As soon as the tiles are laid, they should be covered with a few inches of earth and tramped so that they will not be displaced. If the earth forming the side of the ditch is not fine sand, or if it has sufficient clay in it to bind well, sufficient to pack about the tiles can be cut loose with the spade by the workman standing in the ditch and tramped firmly about the tiles.

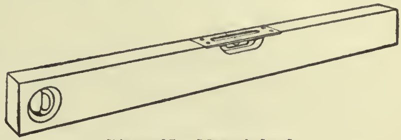


Figure 97. Mason's level.

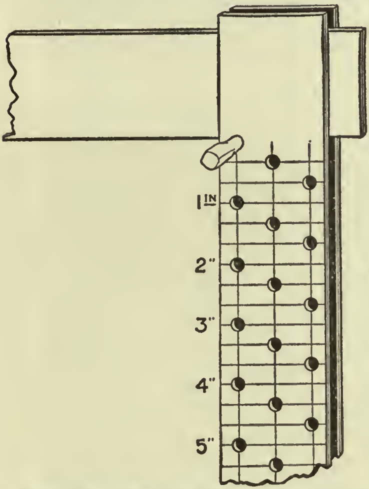


Figure 98. Shows the manner of marking the upright of Figure 96 so that the holes may be bored at the desired distance apart. A horizontal line is drawn through the center of the hole which supports the top board when it is parallel to the bottom board, and another at each inch further down for several inches. Then each inch is divided into three equal parts by lines and three vertical lines are drawn an inch or more apart. By boring a hole at each intersection, the holes are made at intervals of one-third of an inch apart, sufficient to give an added rise in the grade of 2 inches per 100 feet, the bottom board being 16½ feet long.

Where the branches lead off from the line of the ditch, the unions should be carefully made. Union tiles, as shown in Figures 75 and 77, are used for this purpose. Where these are not available, as in case of breakage or long distance from factory, unions can be made by cutting a hole with a cold chisel in a tile on the main line and fitting to this hole the end of a tile on the branch line.

Figure 99. Students leveling bottom of tile ditch with device like that shown in Figure 96.

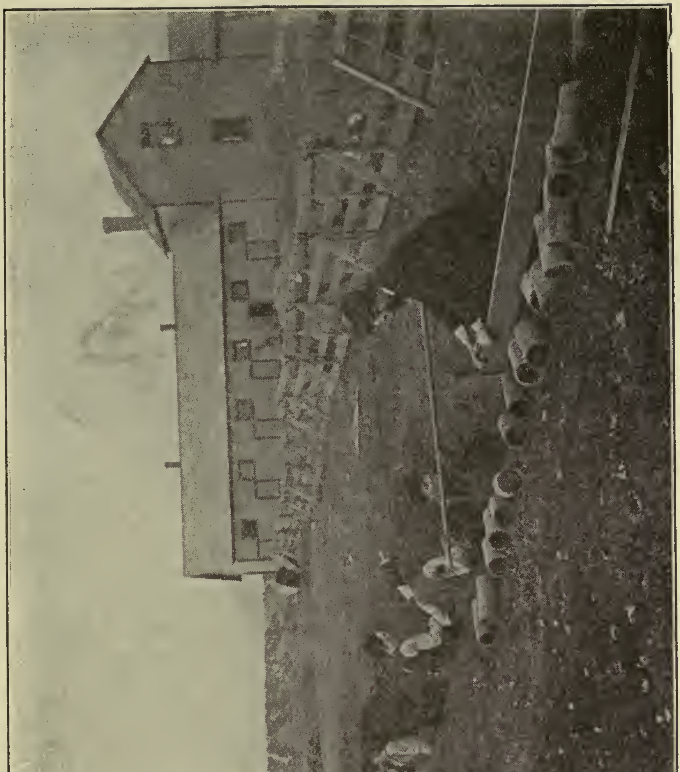


Figure 100. Students of an agricultural high school constructing a tile drain.

This is rather expensive, as the labor is considerable, and several tiles may be broken in the attempt to make the desired fitting. To insure a close joint, broken pieces of tile or stones may be laid or fitted about the rather crude opening.

Protecting the tiles from the roots of trees.—Where the line of drain tile passes under a willow hedge or near other trees the roots of which grow readily in wet ground, there is danger that the roots may enter between the ends of the tiles and by branching within the drain close it up so as to stop the flow of water. Bunches of roots thus formed within a tile drain are shown in Figure 105. By using sewer tiles with shoulders, and closing the ends with cement, these roots may be kept out. This, of course, is not desired in land needing drainage, since the water could not penetrate into the tiles, and is only necessary to thus protect a length of several rods where a tile drain must carry its water past trees.

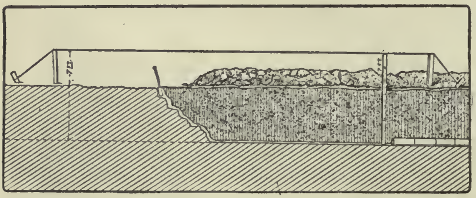


Figure 101. The depth of the ditch having been recorded on the stake at each station, or only in the notes, measurement can be made from the station to a given point above the proposed bottom for the drain, say 7 feet, and a small steel wire, "broom wire," can be stretched between the two stations parallel to the bottom of the ditch. It is then a simple matter to measure down with an L-shaped measure set to determine the proper depth to grade the bottom of the ditch with a tile hoe.

Filling the ditch.—In some instances, the hand shovel is the most practical tool to use in filling the tile ditch. The slush scraper, as shown in Figure 106, may be used to advantage. A chain, 10 or more feet long, is necessary that the team

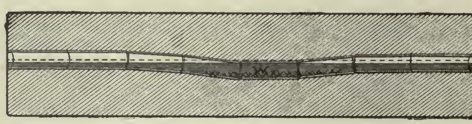


Figure 102. Quiet water in a sag in a drain tile allows sediment to settle there and clog the drain.

may be backed up near to the ditch. Where the ground is solid, the eveners may be carried on the front wheels of a wagon, or better still, by means of the hind wheels of the wagon, supplied with a tongue. The hind wheels being larger can be backed up more easily. One man can sometimes do this work, but a second man is usually necessary to drive the team, at least until it is taught to turn and back at command. A specially constructed scraper, as shown in Figure 107, with a long tongue, can also be used in filling a ditch by having the team on the opposite side of the ditch from the ridge of excavated earth. Some reversible road machines are so built that they can be used to fill the ditch very cheaply, as shown in Figure 108. Before filling with team power, the tiles should be covered by a workman who fills in several inches of earth and treads it firmly about the tiles.

Figure 103. Agricultural high school students laying tile drains, showing how a man can get down into a narrow ditch.

Opening the ditches with machinery.—In a previous paragraph, plowing out furrows with the common plow was advised; in some cases the capstan ditching plow can be used for throwing out the first 18 to 24 inches of earth, thus greatly lessening the amount of hand digging for tile drains.

Tile-ditching machines which throw the dirt to one side of the ditch have been invented, and some of them have been used with more or less success. Others have been devised to carry the dirt backward and throw it again in the ditch behind a man who lays the tiles; and still others which automatically lay the tiles have also been projected and made almost successful in soils which are free from stones and on which the machine can be run without sinking too deeply into soft earth.

Figure 104. Tile hook, handle 7 feet long, hook 10 inches long.

The grade of the bottom of the tile is controlled, in case of machines for opening the drain, by means of levels marked on stakes, above the line of the ditch, with cross bars at a given distance above the desired grade of the bottom of the drain, the operator on the machine keeping the depth of the ditching device under control by sighting from a point on the machine to these cross bars of the successive stakes. Figure 110 shows a mole tile-ditching machine with attachment. A, capstan; B, mole ditching machine; X, man controlling grade of the drain with a wheel and keeping the marker, mounted on the mole coulter in line with markers, O-P, on two stakes so placed as to be parallel with the line of the desired grade. A man sitting in a pit lays tiles on the steel ribbon, F, which is attached to the large steel mole, M, and they are drawn into place. These pits are placed every 50 or 100 feet. These machines have not had extensive use. Capstan mole ditching machines without tiles are also sometimes used in tough clay subsoils, in which the drain may remain open for some time.

Outlets and silt wells.—Outlets need to be carefully arranged, so that stock coming to the mouth of the drain

Figure 105. Masses of maple roots taken from 3-inch drain tiles.

to drink cannot disturb the ends of the tiles by tramping, and it is wise to place a wire screen over the opening, that rabbits and other small animals may be kept out of the drains. Stones laid at the outlet, or masonry built at this point, are sometimes necessary.

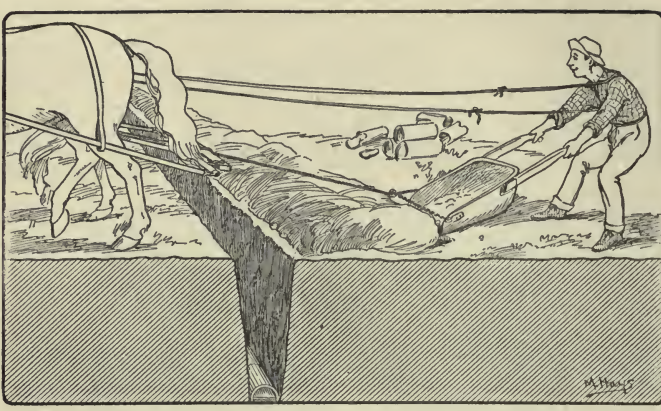


Figure 106. Filling tile ditch with drag or slush scraper.

In other places, instead of the tiles coming entirely to the end of the drain, the last 10 feet may be a board box which cannot easily be displaced by animals tramping upon it. In cases where the outlet of the tile drain must be very low and there is very great need of

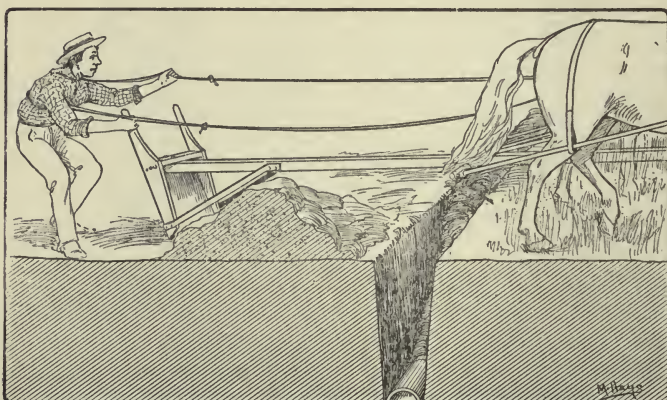


Figure 107. Filling tile ditch with an especially constructed scraper.

keeping the ditch below it clear, it is necessary to build a fence to keep hogs and other animals from interfering.

Cost of laying tile drains.—Where labor costs $1.25 to $1.50 per day, the cost, though varying greatly in different soils, is approximately 10 cents per rod for each foot of depth for tiles laid 2 to 5 feet deep, where the work is all done by hand. Experienced ditchers can make good wages at this price, while inexperienced men will find it very hard to make moderate wages. Where machinery can be used for part of the work, the cost can be materially reduced. In laying 3 and 4-inch tiles that cost an average of $10 per thousand, or one cent per foot, the cost of the tile per rod of ditch is 16½ cents. The cost of digging an average ditch 3½ feet deep is 35 cents, making a total of 51½ cents per rod for the completed ditch. Where the tiles must be shipped on railways the cost will be considerably higher, and for larger sizes of tile the cost is greater. (See Cost of Drain Tiles, page 169.)

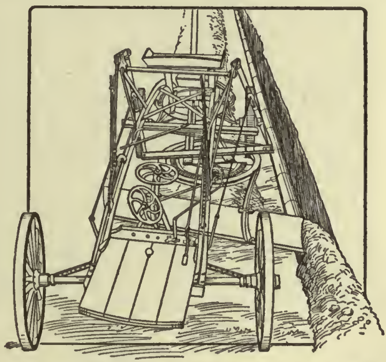


Figure 108. Filling the tile ditch with the reversible road machine.

The cost per acre.—The cost per acre where tiles are laid at regular intervals apart can be closely estimated by using the prices per thousand for drain tiles and adding to this the above estimates for the cost of labor. There are many cases where tile drains are economical where it is difficult to figure the cost per acre, since instead of systematically covering flat areas, the drain follows some low slough or carries the water from some low or otherwise bothersome spot in the field. Here the cost and probable benefit must be compared in some general way, rather than by using the acre as the unit.

MAKING OPEN DRAINS

Capstan plow ditchers.—Very large ditching plows are used for making open ditches in sloughs and in level lands where there are long stretches of alluvial till or

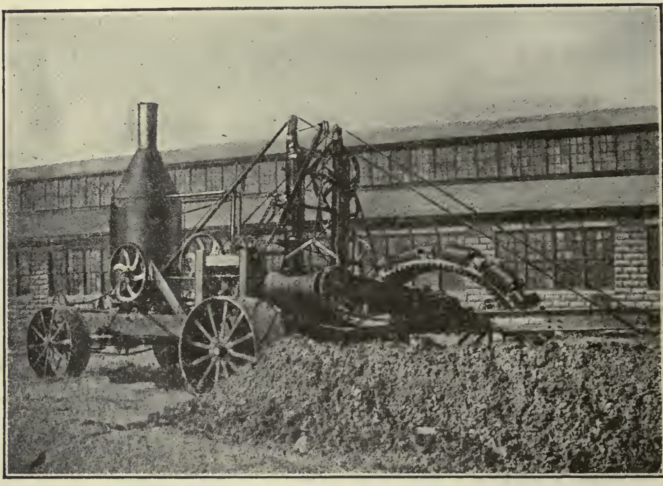


Figure 109. Tile-ditching machine opening a 4-foot ditch.

clay sufficiently free from stones to cause no serious interference to the coulters or lay of the capstan plow ditcher. Generally, the power can be applied in a direct line from the capstan to the machine. In some cases, however, the capstan set in a direct line with the line of the ditch and directly in front of the machine will not give good footing to the horses or oxen on the capstan sweep, and it is necessary, by means of heavy stakes set in the ground, to locate a pulley firmly in the line of the ditch around which the cable can pass to drier land where the horses or oxen can operate the capstan. These same ditching plows are sometimes drawn by twenty to thirty oxen working in pairs or four-ox teams, the teams arranged tandem on the cable. The oxen can pull through rather soft land; yet where the mud is too deep, a long cable must be used and by passing it around a pulley, as before mentioned, the cattle may

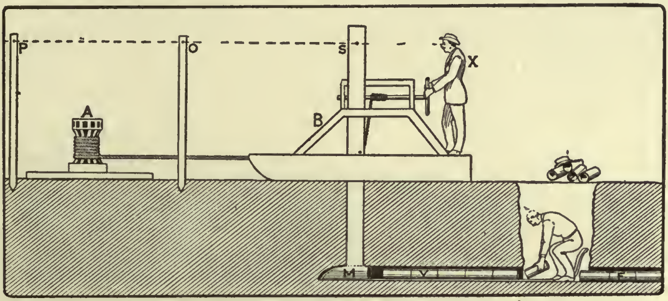


Figure 110. Mole ditcher.

do their pulling on solid ground on one side of the line of ditch.

In tough soils the ditches will remain effective for several years, but finally fill up and become of little service. Such surface drains should be placed at one side rather than on the center of the line, where a permanent drain should some time be placed. A ragged open drain is much in the way in making a permanent tile drain. It is often much easier to construct the permanent drain on a new line where the soil and surface are uniform.

Ditches may be made with these implements at a very low cost, often at 10 cents per rod, or even less. These ditches will sometimes last for a dozen years, or until the farmer can afford a broader open ditch; or still better, a tile drain. In making ditches with the capstan ditching plow, care should be used to have the grade uniform so that the water will run with equal rapidity throughout the various parts of the drain, as this insures more rapid removal of the water and it also prevents the excessive washing which is apt to occur at points of the steepest grades. Wherever washing occurs, there is a certain amount of debris cut loose from the bank, and this debris and other debris washed in from surrounding land is carried forward and deposited in the bottom of the ditch further on and eventually fills it.

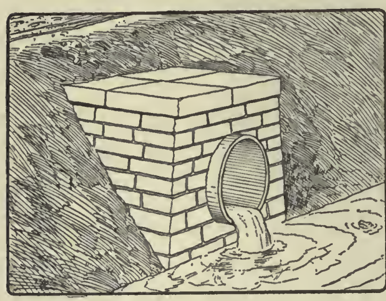


Figure 111. Outlet to tile drain or to earthen pipe culvert.

The slush scraper is also useful in opening out large drains and in filling tile drains.

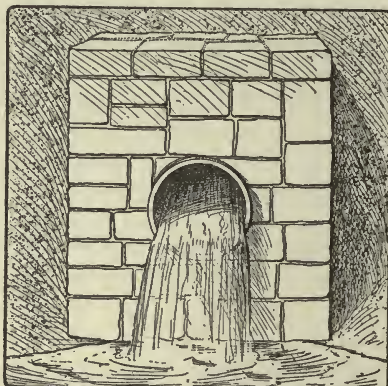


Figure 112. Outlet to drain protected by masonry.

The Fresno scraper is a modified form of the drag scraper much used in the western states. It can be adjusted to shaving off a thin layer of earth and to distributing in a thin layer. It has a great advantage over the slush scraper in moving earth down grade, because more than enough to fill the scraper can be shoved forward. It is made in two and four-horse sizes, and should be rapidly introduced.

The wheel scraper is an improved form of the scraper mounted on wheels, and is adapted to work where the earth must be drawn longer distances than will warrant the economical use of the slush or the Fresno scraper.

The common field plow and the heavy road grading plow are sometimes used in opening out the first portion of small drains and loosening the earth in large ditches

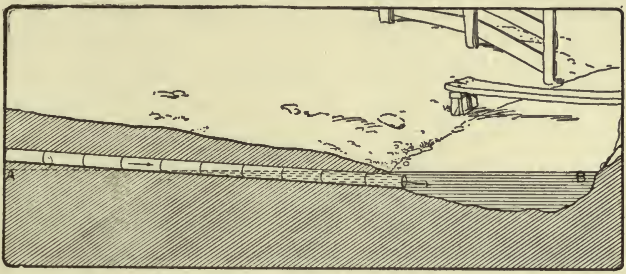


Figure 113. Outlet which of necessity opens under the surface of a stream or pond, thus endangering the tiles from splitting by freezing, when filled with water. A few rods of the drain next to the outlet might better be made of oak boards nailed together so as to form a square box.

where other machinery or even spades are used to take up the loosened earth.

The reversible road machine has come to be recognized as a very important implement in making open drains. With this machine, broad, flat drains can be made which will carry large volumes of water and which can easily be cleaned out by using the same machine. In many cases crops can be grown over the banks and within the broad flat ditches, thus making the drain useful for removing the flood water without seriously injuring the area useful for the common crops of the field. In other cases, these broad, flat drains may be sown to permanent grass and mowed two or more times annually. This insures a ditch free from debris and often crops of valuable forage. Since the use of road machines is described more in detail under the heading of road making, a discussion of their operation will not be necessary here. In Figure 118 is shown the cross-section of a ditch made with a reversible road machine where it is desirable to have the ditch next to a fence with one side not rounded so as to be crossed with teams and implements. The side next to the fence can be left nearly vertical, as at A; it can be made slanting, as shown by the dotted line, B; or, if it is desired even thus close to the fence, it can be made rounded as at the dotted line, C. The earth taken from the ditch can be left in a sharp ridge, as at D; can be thrown up into a rounded form, as at F; or can even be smoothed down by carrying it back on the adjacent land, as at E. This class of machine is not adapted to making very heavy ditches, though, in many cases, the upper portion of the ditch may be opened by means of the road machine.

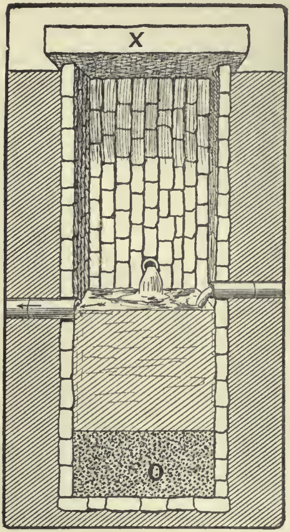


Figure 114. General plan of a silt well, two branch tiles entering and main discharging. The silt accumulating at O by settling in the nearly quiet water should be cleaned out as required, lifting the stone, X, for that purpose.

Figure 115. Drag or slush scraper.

The elevating grader is very useful in opening large drainage canals. This machine does heavy work at a comparatively low cost per cubic yard of earth handled.

Ditching plow.—A very strongly constructed plow

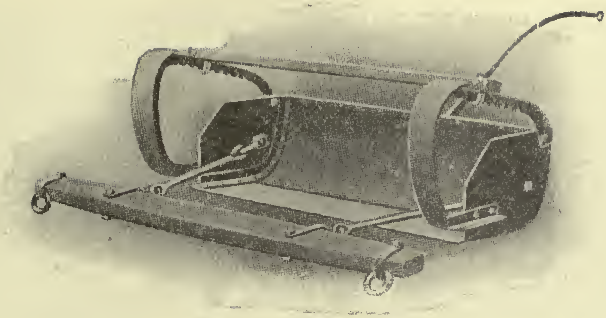


Figure 115a. Fresno scraper.

made to resemble somewhat the common stubble plow and very useful in drainage operations. Either this or the common plow is often used to break up the soil before carrying it to one side with the reversible machine, or

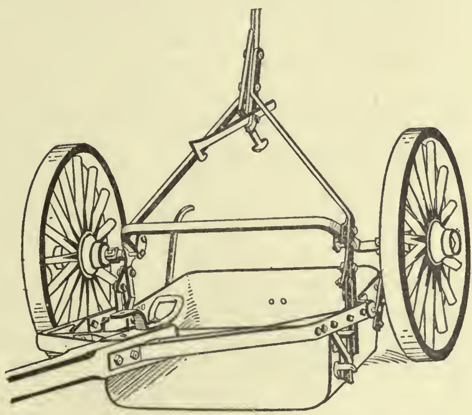


Figure 116. Wheel scraper, lowered for filling.

picking it up with the wheel or slush scraper, or throwing it into wagons with the shovel or spade.

Vertical and special drains.—While most farm drainage can be accomplished by means of either open drains or

Figure 117. Reversible road machine making lateral ditches which run into a large drainage canal made beyond by the elevating grader.

tile drains, there are other forms of drains which are useful for special conditions. Drainage wells are useful where vertical drains can be made cheaply through impervious layers of clay or stone which hold the water in the saucer-shaped area, thus carrying the water downward into the nonwater-bearing stratum of gravel or sand below. In Figure 131 the hills surrounding the low area are so high that a horizontal drain under the adjoining hill would be very expensive. A well is sunk at one side, or if a dry time can be found when the low area is dry, the well can be sunk in the midst of the wet area. Drain tiles, laid from 1 to 3 feet under-

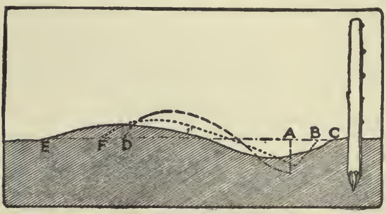


Figure 118. Showing forms of ditch beside a fence line, as at the side of a public highway. A-D, ditch made with steep bank and dirt left in high ridge. B-F, ditch made with slanting outer bank and ridge rounded down. C-E, ditch rounded and earth spread out so that land can be mowed or even cultivated to the roadway, as at P.

neath the surface, receive the water, thoroughly filtered and clear of sediment, and carry it to the drainage well by which it is carried through the impervious layer and

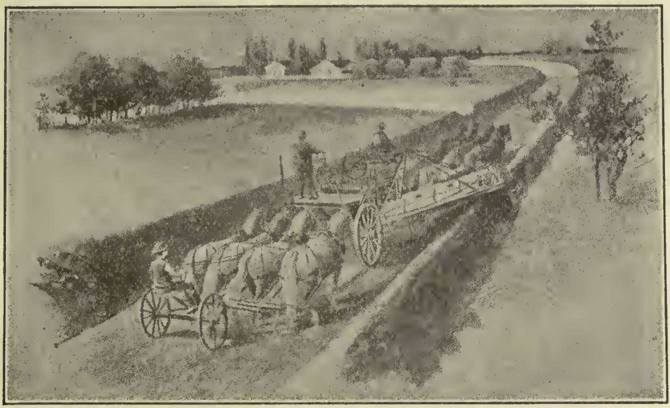


Figure 119. Elevating grader opening large ditch.

enters the loose gravel or sand layer below. If the water were allowed to run from the surface into the drainage well, so much debris would be carried in that the well would soon become clogged and water would

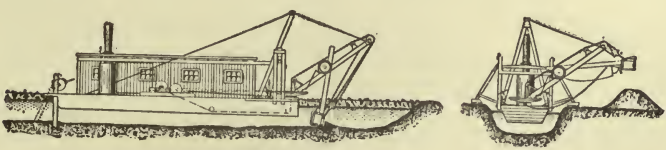


Figure 120. Floating dredge. Longitudinal view showing scoop taking earth out of the ditch in front of the boat. Cross-section showing scoop in position to deposit earth on the bank of the canal.

no longer sink freely through it. However, in some instances, where the impervious layer is near the surface and is not thick, drainage wells may be left open to receive the surface water, and as soon as one is clogged up another can be dug. Where these drainage wells must be dug to a considerable depth, they must be walled with brick, stone, sewer pipe, iron pipe, or even with tubing made of boards. In case of expensive wells, they should be very carefully guarded at the surface to avoid the entrance of dirt, and the tile drains leading into them should be so constructed that all water coming into the wells may be most thoroughly filtered by first passing downward through a few feet of soil. It is essential to know that the stratum into which the water is to be drained has an outlet and sufficient carrying or storage capacity at all times to care for the water which will be brought

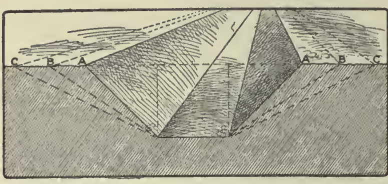


Figure 121. Open ditch with banks 1 to 1, A-A; 1½ to 1, B-B; and 2 to 1, C-C.

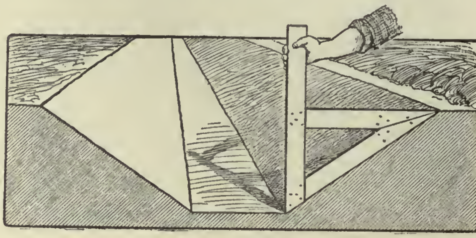


Figure 122. Proper form of surface ditch where earth is firm.

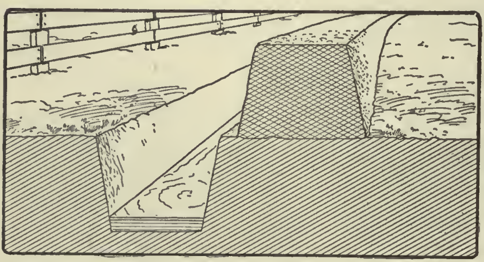


Figure 123. Cross-section of ditch made with capstan ditching plow.

to it. This cannot be determined by the effects of drainage wells upon other similar strata, but only by a knowledge of the *very same bed* of material which receives the drainage for which disposal is sought.

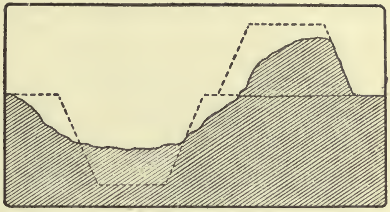


Figure 124. The dotted lines mark the cross-section of a deep, narrow ditch made with a ditching plow, and the wavy line the angle of repose sought by the banks when they have fallen in.

Sewers used to drain lands.—In some situations outlets for open drains can be secured only with difficulty. The water must be carried long distances through neighboring fields or along roadways, and possibly the fall is insufficient to allow the water to run off freely. A deep drain through an adjacent portion of higher land, with a low area on the opposite side, may provide a short but expensive outlet in the form of an open ditch or a covered sewer. In this case, the sewer is not only less expensive, but sometimes better than the wide open ditch, the tiles and narrow ditch costing less than the open ditch. Either drain tile or sewer tile may be thus used to receive surface water at the

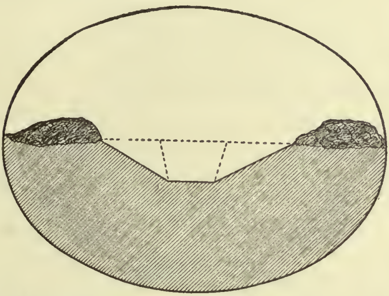


Figure 125. Cross-section of ditch through soil which tumbles or is washed in easily.

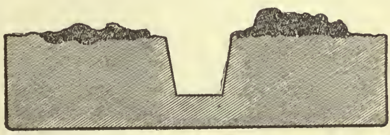


Figure 126. Cross-section of ditch made with spade through peaty soil.

upper end, if sufficient fall can be provided so that the water will run with rapidity and make the ditch clean itself of silt and not become clogged. The distinc-

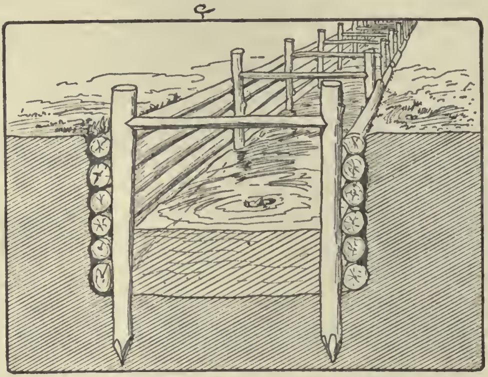


Figure 127. Narrow deep ditch with braced poles protecting the sides from washing.

tion between a sewer and an underdrain may be stated as follows: The sewer receives surface water containing solid materials, while the underdrain, the upper end of which is usually closed by a stone or broken piece of

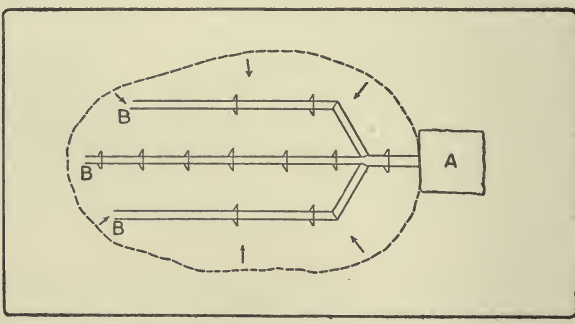


Figure 128. A, drainage well beside a pond. B, tile drains conducting water from the pond into the well.

tile, receives its water only after it has filtered through a few feet of soil and carries very little solid sediment. In cold countries, the sewer will sometimes allow the water to flow through much earlier in the spring than will the deep open drain under the conditions just mentioned, since the ice and snow that will accumulate in the deep ditch must be melted before the accumulated water can begin to flow. This difference often makes it wise to use the sewer rather than the open drain in carrying surface water through higher portions of land. The cost, however, must be very carefully calculated because large tiles and the deep excavations for such sewers are expensive.

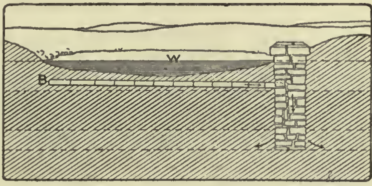


Figure 129. Drainage well beside pond; B, tile drain discharging into drainage well; C, porous earth; D, impervious stratum through which the water cannot sink; E, layer of gravel into which the water entering the well will sink.

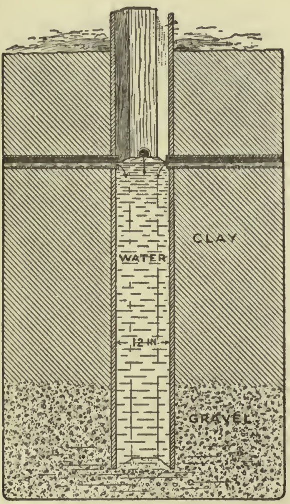


Figure 130. Vertical outlet for tile drains through impervious stratum into stratum which will receive the water from the tile drains.

Stone and board drains.— In the earlier history of drainage, before earthen tiles were used, stone and wood, and even pieces of sod and peat, were used in the construction of underdrains. In Figure 131 are shown drains made of stone laid in different ways. In Figure 132 is shown the V-shaped drain in the bottom of the ditch covered with a plank laid on shoulders of earth, this plank sustaining the weight of the earth thrown back into the ditch, also other methods of using stones and boards in making underdrains.

Underdraining peaty lands.—Instead of tiles laid in the bottom of the ditch in peaty soils, continuous bundles of crooked hardwood poles are sometimes so laid that the water can pass among them and thus run off. See Figures 133 and 134. Where these drains are laid in peaty lands covered with heather, or with other low shrubs, small woody plants can be used to place first over the bundles of poles thus preventing the rotted peat, with which the remainder of the ditch is filled, from sifting down among the poles and clogging the drain. In many cases the tiles may be laid at sufficient depth to be in the hard ground beneath the peat.

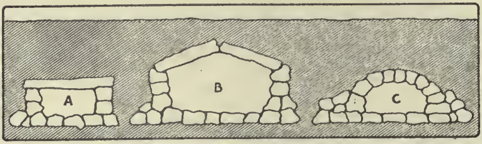


Figure 131. Drains made by laying floor stones in bottom of the ditch, and covering either by laying cover stone on wall stone, as at A, by leaning two stones together, as at B, or by constructing an arch of small stones, as at C.

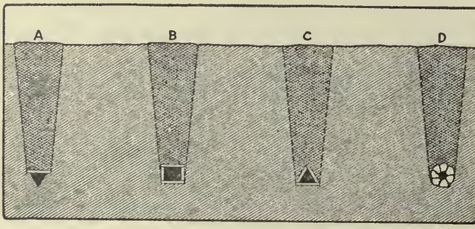


Figure 132. A, drain made by covering a V-shaped groove in the bottom of the ditch by a board resting on shoulders and supporting the earth returned to the ditch. B, C, D, other methods of securing free drainage without tiles.

Dikes, pumps and gates.—As our lands become more valuable the reclamation of fields now covered with water, at the edge of lakes, along rivers, or bordering on the ocean, will repay for draining. Here dikes to keep out the flood water are sometimes necessary. These can be thrown up by means of machinery heretofore mentioned, as in Figure 120. In case of heavy grading works, tram cars drawn by horses, or by other power, may be the practical means of moving the earth. The immense dikes, in part built generations ago, reclaiming large portions of Holland, have thoroughly demonstrated that if the area is large very expensive drains may be economical. Along the Mississippi river immense areas have been reclaimed from flooding by building dikes,

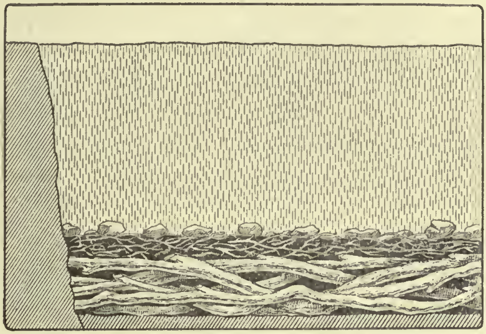


Figure 133.

or "levees," confining the waters to the natural channel. Along many of our streams, beside lakes and along the ocean coast lines, there are large areas which are occasionally flooded or are daily affected by high tide, and as great damage often results to the growing crops, their use for farms is not practicable without control of the water. In Figures 135, 143 and 144, with the subjoined notes, is shown how drainage and irrigation may be combined. By diking and draining with open and tile ditches to a pit from which the water is pumped into the lake, Fields H and I,

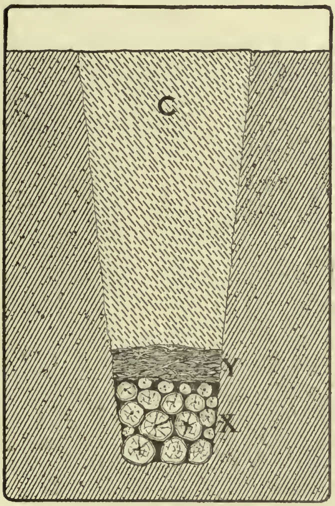


Figure 134.

Figures 133 and 134. Longitudinal and cross-sections of pole drain in peaty land. X, poles; Y, heather or other small shrubs or small branches of trees; C, peaty soil filling the ditch.

Figure 143, are transformed into arable land. Here the same pump serves for both drainage and irrigation. This is a small illustration of how drainage is carried out on a large scale in districts with lands subject to flooding from ocean, lake or river; and it serves also to show how irrigation may be economically arranged on some lands in countries subject to an occasional drouth.

In some cases, co-operative associations are able to undertake the construction of these dikes; in other cases, the county, state, or even the nation must co-operate in their construction and maintenance. Where diking is done there are generally some supplementary arrangements necessary for taking care of the water from the rainfall, and also of the flood water from drainage areas in a direction opposite to that from which the main flood water is held back by dikes. In some cases, water can be drained off in open ditches nearly parallel to the line of the dike, and follow the river to a lower level. In other cases, as along lakes and by coast waters, there is no opportunity for carrying off this surface and flood water, except by elevating it to the other side of the dike by means of machinery operated by wind, steam or other cheap power. The engineering problems of diking and drainage to elevating stations, while representing large interests, do not present unusual difficulties. As a rule, the most difficult problem is to determine the relation between cost and benefit, though in many cases in America, as well as in other

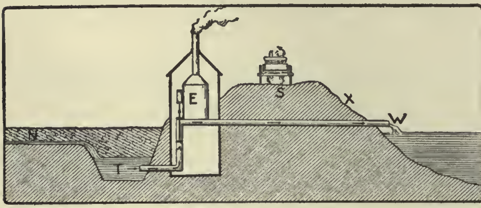


Figure 135. S, roadway and embankment between low area and stream which discharges into the lake; E, pumping engine; T, pit into which drains discharge and from which the water is pumped; W, water discharging into the lake; N, open ditch flowing into the pit; X, embankment beside the lake.

countries, there are extensive areas where the cost of diking would be only a small fraction of the increased value of the reclaimed land. Back water gates are often necessary where diking and draining are combined. Where fresh water is kept off the land by means of dikes, a system of irrigation often can readily be introduced in combination with the drainage.

Open drains should be kept free from obstructions, such as grass, growing weeds and weeds blown in from surrounding fields. The accumulations which arise from banks caving in, or from earth or material washed into the ditch by water or blown in by the wind, as dust from plowed lands, should be early removed, since obstructions of this kind tend to accumulate still more of similar materials. The grade should be kept uniform that any sediment coming into the running water may be carried on to the outlet. Thus, in a ditch carrying considerable water, a slushing device which will stir up the loose mud and help the water carry it forward is sometimes a practical means of clearing the ditch. In some cases a device with shovels, as those from a common cultivator, will answer. A broad board faced with a steel cutting edge and held upright by means of a tongue or by handles, is sometimes used. This kind of a device will not work well except where there is current enough to carry the dirt forward, as finely divided particles, in the water. Much depends upon the kind of soil also. Some kinds of fine clay may thus be carried off rapidly in the water.

Tile drains should be inspected occasionally. The outlet should be visited to learn whether the water is running freely. In cases where portions of drains have been laid through quicksand, which may filter in and fill the tiles, or where for other special reasons clogging is feared, investigations are occasionally necessary to see that all parts of the drains are carrying away the surplus water. Silt wells, or even peep holes, aid in this inspection. Tile drains which are no longer working must be dug up and repaired. Thus drains which have been clogged by roots of trees growing in and filling them with the fibrous mass, must be taken up or, if the trees must remain, sewer pipes should be laid with the collars packed with cement. Properly laid tiles very rarely fail to continue to be indefinitely efficient. In a wide experience the writer knows of only relatively very few tile drains which have become obstructed.

Drainage education.—Education in farm subjects is now making such rapid strides that anyone needing a knowledge of a particular subject can find some means of gaining information along the desired line. The national government at Washington is taking an active part in drainage and other rural engineering subjects. Fifty or more agricultural colleges are dealing with the subject of drainage from the standpoint of the needs of the respective states. Some of these colleges have departments of agricultural engineering, and in these schools men are trained with a general knowledge of rural engineering, who can easily master the subject of any drainage project so as to be useful in planning and superintending the construction of large drainage and diking enterprises. Traveling farmers' institutes are adapted to encouraging neighborhoods where drainage is needed that have not undertaken the reclamation and improvement of wet lands, giving the knowledge, not only of how to unite on some co-operative plan, but also the knowledge of how to secure information as to the details of how drains improve the farm and how the plans can be made and the construction be carried out. The agricultural press contains articles on this subject and agricultural editors will gladly answer questions from farmers as to methods, etc. Bulletins and reports from the United States Department of Agriculture, from the state experiment stations and agricultural colleges of the different states, also the annual reports of the farmers' institutes and state agricultural organizations contain reports on the subject. Associations of manufacturers of drain tiles, of drainage machinery and of farmers and engineers interested in land drainage have done much to promote this subject.

CHAPTER X

IRRIGATION

Since ancient times, irrigation has been practiced in semi-arid and arid countries. Applying water to growing crops by carrying it out into the fields through ditches and allowing it to spread over and percolate into the soil, has assumed immense proportions in the more arid regions of the United States. Even in the states further east than the Mississippi river, irrigation is found very profitable under some conditions. The national government has inaugurated a very large scheme of co-operation in which, through an organization called the Reclamation Service under the Department of the Interior, it joins with many landowners and aids prospective purchasers of public lands in the construction of immense systems for irrigation. In some cases canals are built taking water directly from streams to the land. In many cases dams are necessary to raise the level of the water in the streams from which the water is drawn. In other cases immense dams are made to create great storage reservoirs in which supplies of water are accumulated to be used when the crops most need them. The United States Department of Agriculture also is doing much in co-operation with private parties or organizations who are irrigating lands. This department is aiding not only in making plans for irrigation plants both by the gravity plan, and by pumping by wind or other power, but it is also studying methods of distributing the water to the farmers and to their crops, and is investigating methods of farm management under irrigation. The engineering plans being worked out by the Reclamation Service alone involve many millions of dollars and with the co-operation of the United States Department of Agriculture will make many thousands of irrigated farms available for farmers. Care is being used that these lands may be divided into family farms and thus made to serve well the largest possible number of people and to increase the number of America's farm homes. This constitutes the most extensive irrigation scheme ever undertaken, and is one of the most ambitious engineering feats ever entered upon. It is a public enterprise which will again prove the ability of a republican form of government to

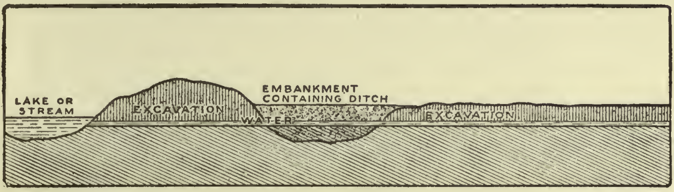


Figure 136. Showing ditch from stream, lake or reservoir through excavation, on an embankment, across a low area, and through land at grade.

carry out large national movements which benefit the whole people. Through this work the United States government is extending its policy, inaugurated through the national homestead law, of dividing the land into family farms.

Not only is irrigation profitable in arid and semi-arid countries, but also in countries where the rainfall is not evenly distributed throughout those months in which crops make their greatest growth. Irrigation on a large scale is practicable only where streams, lakes, rivers,

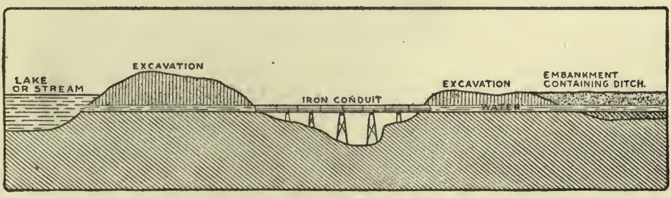


Figure 137. Showing ditch extended across a low place through an iron conduit supported on trestle work.

Figure 138. Windmill and storage reservoir for irrigation water.

artesian wells or artificial storage reservoirs furnish large supplies of water. Someone has illustrated the limitations of irrigation in the great arid West by comparing the whole droughty plains and intermountain areas in which the rainfall is light to a twenty-acre field with one furrow plowed across it, the furrow representing

Figure 139. Portable engine used for pumping water for flooding rice fields in Texas.

that proportion of the whole for which the water is available for irrigation. The semi-arid area on which dry-land farming must be carried on is very extensive, and farm management there must be planned to conserve, for the use of crops, the small amount of water annually precipitated. In many places the windmill, or steam or gasoline engine to pump water from wells upon limited areas, as near buildings, will help make possible the development of a homelike farmstead on large ranch-like farms in semi-arid regions, and will give some food for man and beast, even in the exceptional years of least rainfall, and will help make the farm pay in all years.

In regions like Minnesota, on the other hand, the many streams, the thousands of lakes, the large quantities of available well water, the less amounts of water required for irrigation where the rainfall is nearly sufficient, and the possibility of storing surface water in large artificial reservoirs, will make it comparatively easy to irrigate large areas of land. Good lands have been so cheap that farmers and gardeners have only begun to appreciate the fact that at no distant date the higher price of lands, together with the cheapened machinery and possibly cheaper labor, will make irrigation profitable in many places where the rainfall has been heretofore wholly depended upon.

Sources of water.—The bulk of irrigation is now done where the water is obtained from mountain streams or rivers so situated that the water may be led out, by means of canals and ditches, to lands which are nearly level, in the valley lower down the stream. These ditches are usually laid out with a very gentle slope, through the low lands or around the borders of the hills. Branches from the main canal are led off to the various tracts of land to be irrigated, where the ditches are further branched and the water carried to the farms and fields. In many cases, lakes and reservoirs are employed in which to store up flood water for use during the dry season when the water in the streams is low. In other cases, the storage capacity of lakes has been very greatly increased by means of dams across their outlets.

Storage reservoirs are being made in many places by building dams across valleys, thus conserving large quantities of water which can be led out and spread over the fields in times of drought. As a rule, these storage reservoirs are filled by the flood water which naturally flows through the valley in the springtime, but which is saved up for use in the summer. In some cases the water which is used to fill the reservoirs is provided by springs and artesian wells. These form comparatively small streams during the entire year, hence storage reservoirs are necessary to store up their water that it may be available for use in the season of plant growth. In some instances the water from springs and wells, instead of being carried to tanks or other reservoirs to be used for garden and orchard crops, or even for field crops, is spread directly upon the fields.

Where vegetables, fruit or other crops which bring large amounts of money per acre, are grown, a large expense per acre can be put into irrigation with profit. These valuable lands, under intensive cultivation, require a large expense for seeds, manures and labor. Rather than risk the loss of these investments, it is often wise to invest sufficient money in an irrigation plant to water the crops, and thus insure the larger yields and high quality which will bring an income sufficient to pay expenses and leave a larger profit. In dry years, when other growers have short crops, the farmer who is prepared to irrigate secures both a large crop and high prices for his produce.

Legislation.—A prominent jurist recently said that irrigation laws were becoming one of the most complicated features of American jurisprudence. No attempt will here be made to more than analyze the general principles upon which these laws are constructed. The water of streams which passes through the lands of many owners is recognized as belonging to the public rather than to individual citizens; at the same time, this water is for the use of whoever can utilize it. Since expense must be incurred in preparing to use water, either for irrigation or for power to be employed in manufacturing, the public must recognize that landowners who build irrigation ditches, or manufacturers who construct dams, are entitled to consideration, and that they acquire rights which the public must respect through suitable legislation and court decrees. Thus, if one man or firm builds an expensive irrigation canal through which is conveyed all the water from a

Figure 140. Stationary engine raising water by steam power on rice fields in Texas, where thousands of acres are irrigated by means of very large pumps.

stream and makes use of it upon fields, a wrong would be done if another man or firm were to make a similar irrigation canal further up the stream, thus intercepting the flow of water and causing the first party to lose the value of the expenditure in making the first canal. The second party, however, might properly make a canal further up the stream if he used only part of the water, allowing sufficient to flow to the first canal to furnish all the water there needed. In case of large streams still other canals can be built and eventually the public can recognize through its laws and court decrees that each party has a right to a certain amount of water.

In case of successive years of small rainfall, there might be water sufficient only for the needs of the farmers along the canal first built. In this case, the parties interested in the canals constructed at a later date must properly give way and allow the water to be used by the parties who made the first ditch, even though it is further down the stream. In years when there is not water enough for all, the proper division of the available water is a difficult matter, and in many cases laws have been designed under which officials of the state act in making an equitable division of water according to the rights and needs of the several parties interested.

While priority of right is thus recognized, it has been found difficult to frame laws under which the rights of all can be respected and the best interest of the largest number served. The land which is available to irrigate with any given supply of water is entered at different times; having been purchased or homesteaded from the government or secured in other ways, as by grants to railways, etc. The irrigation ditches are begun by the government, by individuals and by corporations, who in turn subdivide their lands by selling to individual owners. The relations among promoters of irrigation ditches, and between these and owners of the land, become very complicated. The various states of the arid west have enacted many laws to deal with these complicated conditions. These laws have generally been made by piecemeal and are sometimes aptly termed "patch quilts." The decisions of courts in dealing with litigations in individual cases have been numerous and often conflicting. Thus, the network of legal relations concerning many of the irrigation enterprises in the West are exceedingly intricate and in many cases most embarrassing, often stopping the utilization of valuable water supplies because of the unsettled legal problems connected therewith. The general government is not only studying these problems, but has entered upon a vigorous policy of overcoming the difficulties of co-operation in making the best possible use of the available supplies

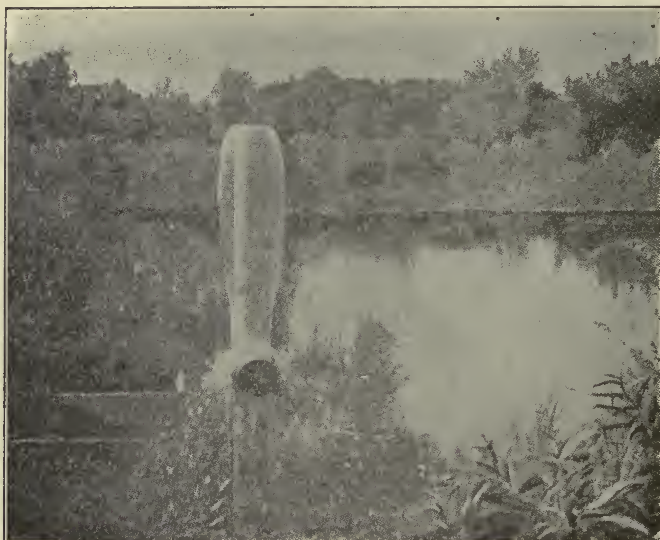


Figure 141. Flowing artesian well in Nebraska. With nine wells, with 6-inch pipes, 112 acres are irrigated for very slight cost. (U. S. Geol. Survey—Irrigation Paper 29.)

of water. States which have not as yet enacted laws relating to irrigation have a great advantage in that they may start with general laws in which are recognized the general principles as emphasized by the best business and legal experience in the drouthier states which earlier began the use of irrigation waters.

Irrigation laws should recognize, in some comprehen sive way, and in sufficient detail to meet the varied conditions, the priority of the right to use water as acquired by those first entering upon such use. That the state should, in some instances, reserve the ownership of the water and the right to regulate its use, or even after a certain date demand a rental price, is advocated by some people. These laws should contain regulations under which public officers and officers of co-operative associations and private irrigation companies must work in distributing the water to the various citizens and individual users.

Proper provisions should be made for the appointment of competent officials under some system of civil service. Suitable means for locating, altering and even discontinuing irrigation ditches and aqueducts should be provided. Comprehensive laws should deal with the construction and maintenance of public irrigation canals and the distribution of the water to the adjacent land. However comprehensively a state may devise its general law, special and minor laws will be necessary. Penalties for injury to canals or gates and for the unauthorized use of water are necessary. In all states where irrigation waters are likely to be used, laws under which water rights can be secured should be passed, and the county or state engineer should be required to make surveys with proper records of all claims at the time the rights are entered upon for water available for irrigation, and these records should be evidence of priority of rights. These records should include a record of the size of ditch used in leading the water away from any stream or lake.

Water rights often conflict with the rights of those interested in transportation by water. Especially is this true with owners of water powers and with logging companies who desire to use the flood water from rivers, lakes and reservoirs to aid them in floating their logs to the mills and near to their markets.

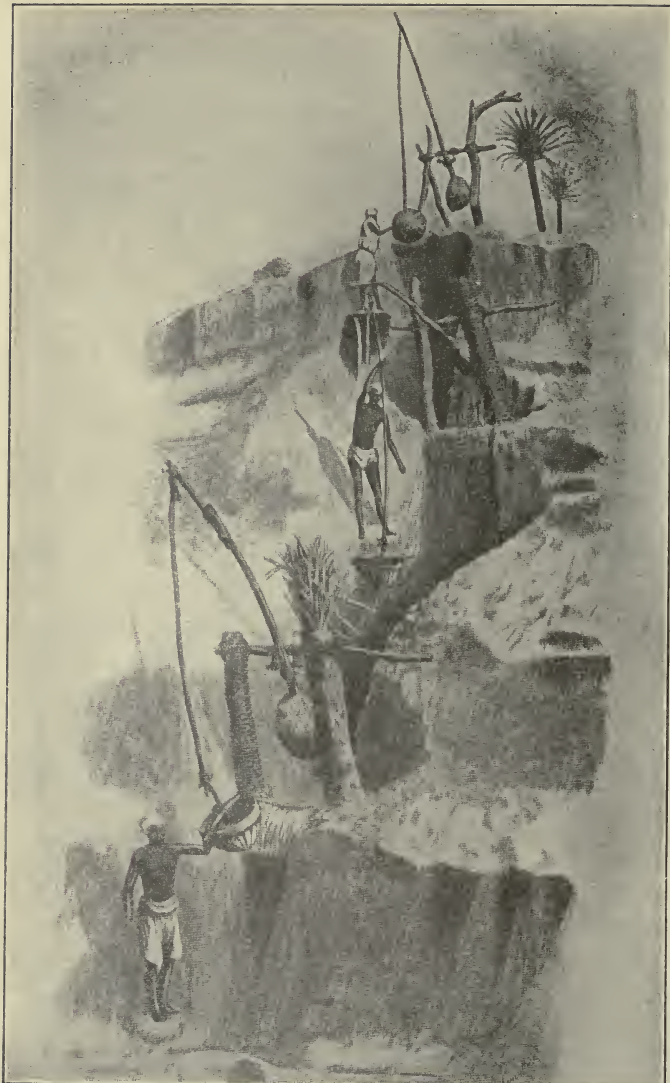


Figure 142. Raising water by hand in Egypt. (Bul. 130, Office of Experiment Stations, United States Department of Agriculture.)

Most efficient arrangements are being worked out to meet all the conditions of law, of ownership of water rights and lands, of irregular supply of water, and of seasonal needs of crops under large irrigation canals. By combining storage reservoirs with the regular summer water flow, by arrangements for exchange of rights to water at given times, and by other devices, associations of water users, through their officers, can utilize water to the best possible advantage. The building of reservoirs in which to store up flood water has only begun to utilize the vast resources of this class of waters.

Surveying and mechanical appliances used in irrigation construction are mainly the same as those used in making drainage systems, as illustrated on previous pages.

Irrigation canals must have sufficient fall so that they will carry the required amount of water, but should not have so much fall that the water, in rushing through them, will wash or destroy their banks. The aim is to give a velocity that will prevent the deposit of silt in the main canal and not cause serious erosion. Three feet per second is the usual maximum velocity. The grades of western canals and ditches vary from 6 inches to 50 feet per mile. The more nearly level the grade, the larger must be the cross-section of the ditch. The engineer must make the calculation in each individual case and decide upon the plan which will accomplish the desired results in the best manner and at a minimum expense. In case of aqueducts of wood, stone or metal, where the danger of injury from rapidly flowing water is slight, much is gained by having the grade steep so as to have a larger amount of water flow rapidly through a comparatively small, and therefore less expensive, aqueduct.

Wood and iron aqueducts.—In many places it is necessary to carry the water across low areas. In some cases, aqueducts can be made by building a grade of earth or of masonry, as in Figure 136. In other cases the depth is

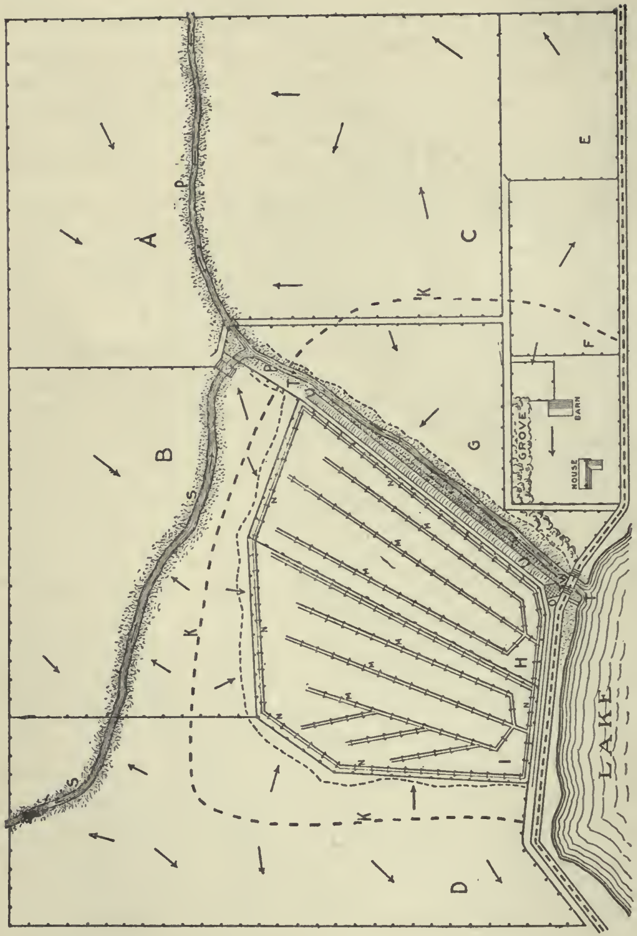


Figure 143. Fields H and I, level with the surface of the lake, are drained to O beside the road embankment, which dams the lake water back from the land. The water can be pumped from the reservoir, O, by pump at W, and forced up to K, the highest part of the fields adjacent and from there spread in irrigation ditches to the fields.

so great that aqueducts of wood or iron are necessary. Most of the irrigation, however, can be accomplished by means of earthen canals, though, in many cases, more expensive structures have been made to produce handsome profits

Machinery for elevating water.—Much is being done to devise methods of elevating water by machinery. Steam and gasoline engines and windmills perform the great bulk of this work. In the rice-growing regions of Texas and in arid regions, large engines are used to pump the water from streams or reservoirs, or from wells, thus, in some cases, directly supplying vast tracts of land when the crops especially need the water. In other cases the water is pumped into reservoirs to be available when needed by the crops. Windmills and small engines are often used on farms to utilize a small amount of water from wells or other sources to irrigate the farmstead and perchance a small area of fields. Especially is this advantageous in dry regions where most of the land is used for pasturage, or is subject to years of serious drouth. Here the limited acreage of irrigated land greatly aids in tiding over the dry years, as well as adds to the products in the years of more ample rainfall. The storage of pumped water and its distribution through open ditches is carried out much as in case of water secured by gravitation.

In Figure 143 is shown a farm with four large fields, A, B, C and D; three small fields, E, F and G; and two very rich fields, H and I, from a reclaimed swamp, the surface of which is practically on a level with the water in the adjoining lake. All fields are fenced. The area surrounded by the line, K, incloses all the land which drains into this low area. The stream, P, P, receiving the water also from the stream, S, S, was not well defined from T to T. If straightened and deepened between these points, and if the earth excavated be used for an embankment, U to U, the water can be carried directly to the lake without longer flooding the flat area. Since the flat area receives only the water from its own surface, and from small parts of fields, B, D and G, and since the subsoil is too dense for seepage water to come in from the adjacent streams and lake, it can be drained by draining it into a pit and pumping out the water, as shown in Figure 144. The drainage is accomplished by means of a system of tile drains M and N, or N (Figure 143) can be an open drain, all leading to the pit, O, from which the engine at W can raise the water a few feet and discharge it into the lake (as shown at W, Figure 143), across the road embankment, which keeps the water out of the low area, or send it through a pipe (as shown at L, Figure 144), to the crown of the low

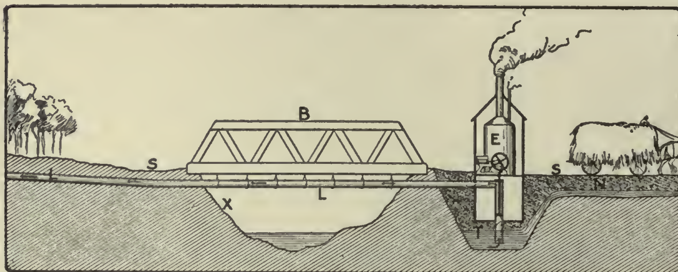
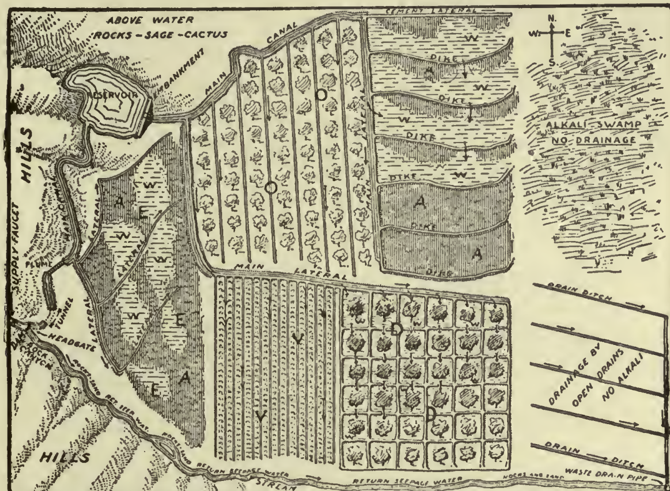


Figure 144. E, pumping engine; T, pit into which drains discharge, and from which irrigation water is pumped; B, bridge across stream; S, roadway; N, open ditch along roadway; X, embankment confining the stream; L, line of pipe, through which irrigation water is carried to fields.

hill at K, K, K, where it can be spread out through open ditches and used for irrigating fields, F, E. C and G. When the drainage ditches from fields H and I do not supply water for irrigation, water can be pumped from the lake or from the stream, P, P.

Farm irrigation schemes.—The layout of a farm which is to be irrigated is often a more complicated engineering proposition than the organization of a farm in a climate where the natural rainfall is depended upon. The main field supply ditches often are the best field boundaries. A system of ditches, furrows, check system embankments and ditch openings must be devised for each field and each orchard. Often a system must be provided to remove seepage water from lower lands, and, where seepage waters evaporate, even to prevent or cure alkali. In planning the irrigation scheme a plan of crop rotation should be also devised which will arrange for the most profitable use of the land and water.



A = ALFALFA W = WATER V = IRRIGATION OF VEGETABLES BY SMALL FURROWS
O = IRRIGATION OF ORCHARD BY LARGE FURROWS D = IRRIGATION OF ORANGE ORCHARD BY THE CHECK SYSTEM E = IRRIGATION OF ALFALFA BY FLOODING SLOPE GREATER THAN FOR REST OF IRRIGATED PORTION ═ = EMBANKMENTS GENERAL SLOPE. NW TO SE

Figure 145. Drawing of a model of irrigation plan displayed in plaster at the St. Louis World's Fair.

That these should be devised at the same time is manifest, since the system of applying the water and the times of applying it must be adapted alike to all crops in the rotation scheme. The organization of farms, and especially the planning of irrigated farms, is destined to become a technical profession needing men skilled to assist the farmer in working out his own knowledge and ideas into an organized plan which will enable him to make profits. Like rural architecture, the planning of family farms deals with small units, hence a professional class of rural engineers skilled in this work has not yet been established. As yet there is a comparatively small number of engineers prepared to earn the fees which wealthy men are willing to pay for plans for the organization of their large estates. The basic data are being wrought out which will eventually so serve the man trained in using water and in organizing irrigated farms that he will be of great assistance to the general irrigation farmer. The support of such men at public expense is coming to be recognized as a very proper way of providing a certain kind of teaching called demonstration farming. The farmer, the expert trained in using irrigation water, and the principal of the consolidated rural school, co-operating, can often work out a plan for a new farm, or can plan for the reorganization of an old farm. The students of the consolidated rural and village school can have the benefit of the various steps in devising the plans, in developing the farm under the new plan, and in studying the figures and facts resulting from putting the plans to the test in the production of crops and in the yielding of profits to the owner.

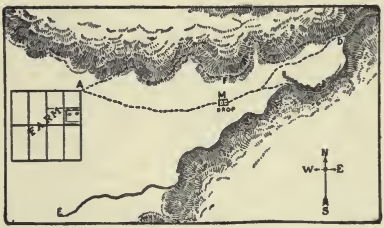


Figure 146. Trial survey line and adopted course for main canal from D, past M, to A.

In Figure 145 some features of irrigation are illustrated by means of a drawing showing a model plan in plaster of paris exhibited at the World's Fair at St. Louis by the American Association of Agricultural Colleges and Experiment Stations. The water is represented as conveyed through a main canal to a reservoir and from there conveyed through a continuation of the main canal, main is raised into the main canal by means of a dam in the stream supplying it. The main canal is shown as passing through a tunnel under a rocky ridge, through a flume across a ravine, and into a reservoir where a small flow of water is accumulated for use when needed by the crops.

The map shows the manner of carrying water to the respective fields and of distributing it by flooding on sloping land, as on alfalfa in Field E; by flooding be-

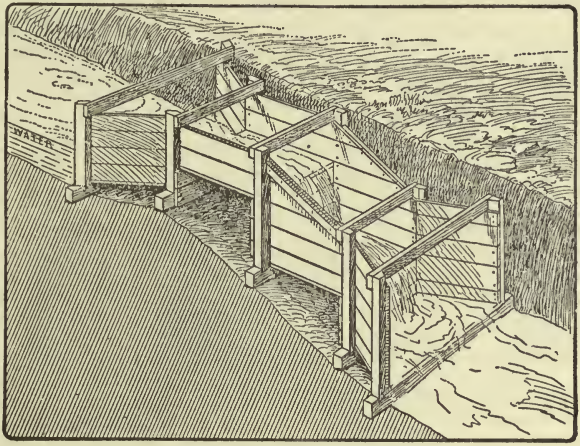


Figure 147. Ditch drop to carry the water of a ditch to a lower level.

tween dikes on land not quite level, as for alfalfa on Field A; by large furrows, as in the orchard in Field O; by small furrows, as for vegetables in Field V; by flooding in a check system, as the orchard in Field D. An alkali swamp is also shown, and beside it a swamp with no alkali, drained by open ditches. In many cases alkali swamps located like the upper one are benefited by underdrainage. Since irrigation structures are usually permanent there is especial reason for the use of great intelligence in making plans which will best serve the purpose; and for great care in building the ditches, dams and gates.

Conveying water from source to farms.—Choosing the point at which the main canal will receive the water from the stream, lake, reservoir or pump; deciding upon the course of the canal, and planning the head gate and the construction of the canal, with any necessary flumes, tunnels and drops, often form a complex problem. In large and complicated projects only trained engineers experienced in this class of work can assemble the necessary facts upon which to base judgments and can devise plans which will serve in carrying the water effectively and economically. Experts in soils and farm management are needed to form difficult judgments as to the value of lands which it is proposed to supply with water at large expense, that enterprises be not undertaken which will not prove to be profitable.

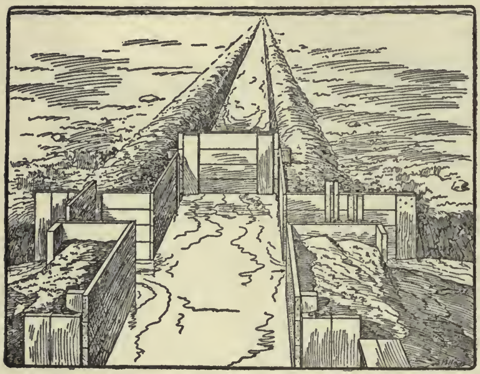


Figure 148. Division box, showing how part or all the water can be turned from a ditch into laterals. (After U. S. Farmers' Bulletin, 263.)

In Figure 146 are shown two lines of survey made in the selection of a ditch line from the highest part of the Farm A to some point on the stream D, E. D is found to be the practical place for the head gate. The trial line, D, F, A, following a gentle grade about the bases of the hills, makes too long a line and some rocky excavating is necessary. By placing a drop at M to drop the water to a lower level, the main ditch can go through land in which a canal can be cheaply constructed.

Often it is necessary to drop the level of water in a ditch to avoid long ditches around hills or to avoid too much fall and thus prevent erosion by too rapid flow of water. The general plan of structure with boards, shown in Figure 147, can be followed, or a permanent waterfall may be constructed of stones or cement.

Water gates.—In all complicated systems of irrigating canals, gates and weirs must be employed to be used in restraining the water and in directing it into the desired channels and fields, also to measure out the proper amount of water to each party entitled to water. In Figure 148 is shown a system of three gates. The gate in the main ditch is raised so as to hold the water above it at an even height. The side gates are raised to discharge a given amount of water, as determined by a measuring weir below each gate. In Figure 149 is shown a simple head gate used by a farmer in regulating the water which he desires to flow upon a given field. In Figure 150 is shown a side or head gate used by a company to regulate the water which its ditch

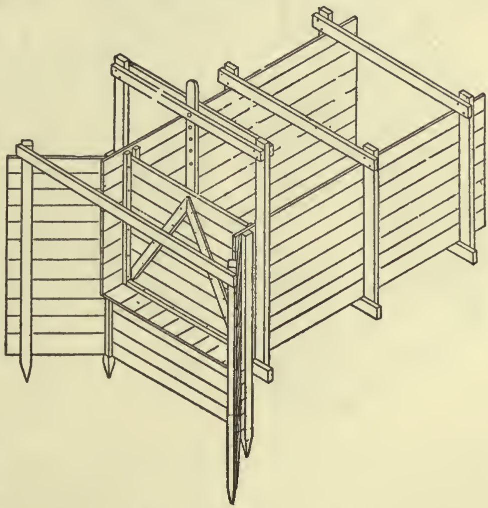


Figure 149. Simple head gate.

agent allows to flow into the supply ditch of a farmer. By means of the wheel and screw-rod the gate can be raised to allow a given amount of water to pass through. The arm-nut with chain attached can be so placed on the screw-rod as to allow only the allotted amount of water to pass under the gate, and with padlock it can be locked so that no one can open the gate wider. In Figure 148 is shown a form of division box by means of which part or all of the water can be taken from a main ditch and distributed to the ditches either side. The gates, usually made of 2 x 4-inch uprights and 2-inch planks, can be so adjusted as to permit the desired amount of water to flow through them. In case of ditches which carry water to a number of users, each of whom is entitled to a share, the openings in the gates are adjusted to measure the water supplied through the four laterals, that each may receive his proportionate share.

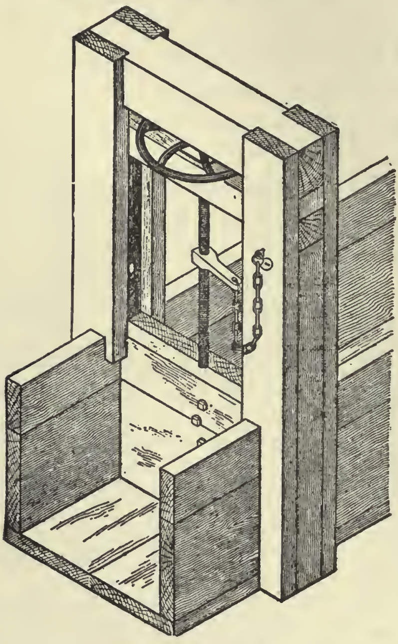


Figure 150. Head gate used for regulating and measuring water from company ditch to farmer's ditch.

The measuring weir, usually placed in the ditch just below the head gate, is a very simple device, by means of which the amount of water running through the ditch can be measured. Thus the corporate company or the co-operative association of farmers can determine the amount of water supplied to each farmer; and the farmer can determine the amount of water allowed to run upon a given field. Weirs are so constructed in relation to the opening in the water gate in the ditch above that the water in the weir stands at a uniform height, that it may flow out of the weir with a stream of uniform size and velocity. The standard or unit used in the measurement of flowing water is usually the cubic foot per second of time. Thus a head gate so adjusted that it allows a cubic foot of water to pass through the weir each second

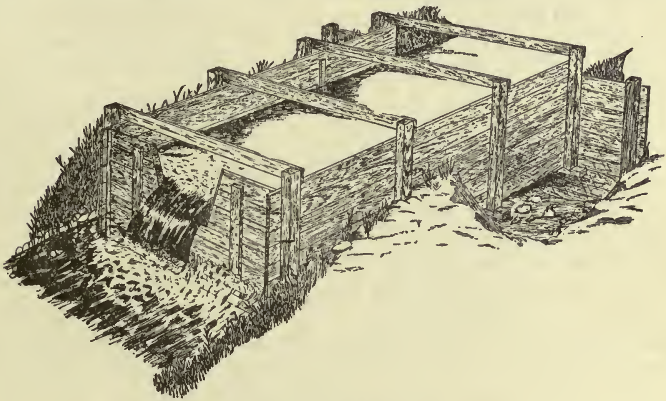


Figure 151. The measuring weir.

is said to be adjusted to one cubic foot or one foot of flow per second. The head gate can be adjusted to 20 cubic feet per second or to any other amount. And after adjusting the head gate to a given flow the superintendent of the canal can leave it one or more days with the assurance that the flow will be practically uniform for the full time required to give the farmer his allotted share of water.

The measuring weir is simply a notch of a certain shape and size in a dam placed across a stream, so arranged that all the water flowing in the stream passes through the notch. The Cippoletti weir is a notch of a given form, and formulæ have been constructed to apply to the depth of the water flowing out, by this means reducing the record of outflow to cubic feet per second. In Figure 151 is shown the weir in perspective; and in Figure 152 the form of notch, with measurements, is shown in detail.

Since the level of the water at the point where it flows out of the notch is somewhat depressed the measurement of the height of the water above the knife edge, or bottom of the notch, is usually taken some feet from the notch. This may be arranged for by having a peg driven in the ditch, the top of which is level with the knife edge, that by means of a pocket ruler the depth of the water may be measured; or a graduated measure may be attached to the side of the weir box, as on the left side of the box in Figure 151.

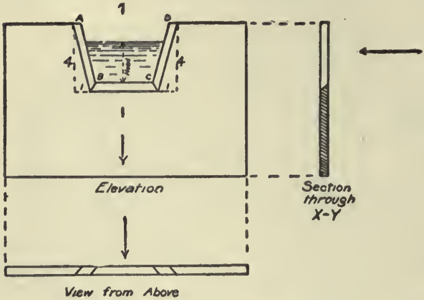


Figure 152. Details of weir board.

The construction of the weir box 8 feet long, 4 feet wide and 3 feet deep, of 1 and 2-inch lumber, as shown in Figure 151, will cost \$5 to \$9. The floor is extended beyond the lower end to serve as a platform to prevent the falling water from washing out the ditch, and where needed the sides of the ditch may be further protected by riprapping with rock. The weir is more accurate if the notch is chamfered with the sharp edge up stream. The weir box should be large and deep in proportion to the opening of the notch, that the stream may flow out with perfect freedom and uniformity. The miner's inch is also used, especially in regions where miners have become accustomed to distributing water to be used in mining. The miner's inch is the amount of water which

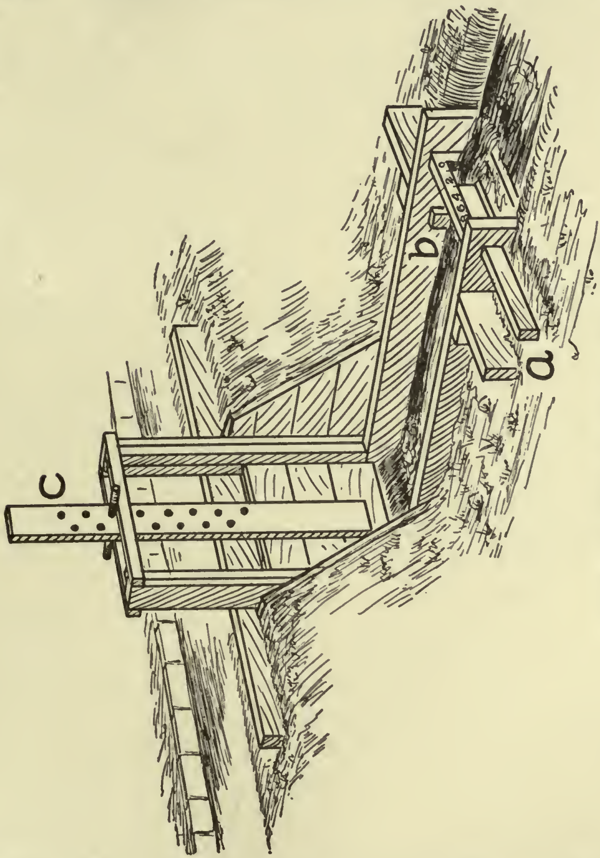


Figure 153. Box for measuring miner's inches.

will flow through a square inch of opening in a second with the water held at a given height above the opening. The exact conditions for measurement are defined by law in most of the western states, the conditions differing in different states.

In Figure 153 is shown the construction of a box for measuring the flow of water in miners' inches. Formulæ are also used for the calculation of the amount of water flowing from weirs of a given construction with the water above standing at a given height. The United States Department of Agriculture, the State experiment stations of Colorado, Wyoming and other states, have published bulletins treating of the measurement of irrigation water, which can be secured by those needing detailed information.

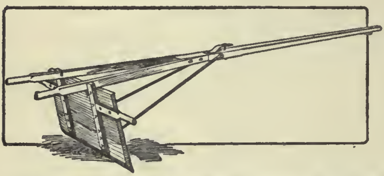


Figure 154. Plank scraper for opening irrigation ditches.

As a unit of measuring water for irrigation purposes, the miner's inch is not so generally used as the cubic foot per second, or the acre foot. In recording measurements of large quantities of water, the miner's inch, although fairly accurate, is too small a unit.

"The miner's inch is a unit of rate of the discharge of water expressed in terms of a standard orifice or outlet opening, usually 1 inch square, and a standard head."* In different states this head varies from 3 to 9 inches, but the head most commonly used is 6 inches. "Under a head of 6 inches and coefficient of 0.62, the discharge through a 1-inch orifice would be 0.0244 cubic feet per second or 0.183 United States gallons (of 231 cubic inches). Usually the orifice is of fixed depth and adjustable length." (See Figure 153.) The standard head of 6 inches (in sketch the head is marked by block B, 6 inches long and tacked on side of box), or whatever head it may be, is maintained by the gate C. This gate is placed securely in the ditch bank and raised or lowered

* Trautwine's Engineer's Pocket Book.

according as more or less water is being drawn above the orifice. The amount of water let through under the constant head is regulated by the slide A shown in Figure 153.

An acre inch means sufficient water to cover an acre of land an inch deep, and is 226,875 pounds, 28,359 gallons, or 886 barrels of 32 gallons each.

Constructing farm supply ditches and field ditches.—The location and construction of ditches to carry the water to the fields can be done with the reversible road machine, Fresno scraper, especially devised scrapers, the

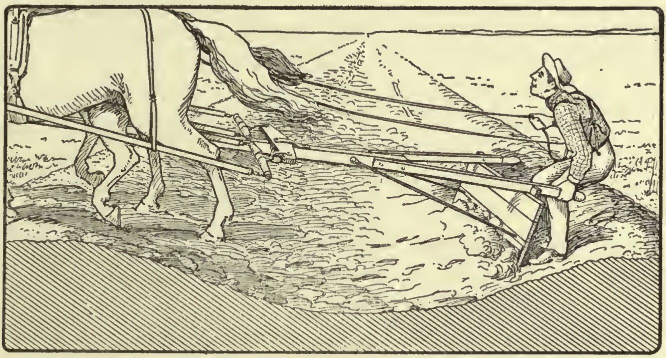


Figure 155. Showing plank scraper in use, placing the embankment all on one side of the ditch.

road plow, the common stubble plow, the spade and other suitable implements. In many cases the earth from the ditch can be made to serve as an embankment in checking off nearly level fields or in terracing the hillsides with slight fall so as to hold water in flooding.

Locating field laterals.—In making shallow laterals through the farm, and often temporary ditches through the fields, it is necessary to curve about small elevations so as to have only very slight grade to the ditches.

The biped level shown in Figure 158 is used in mapping out field laterals around slight elevations. Laterals nearly level make it possible to take water out through small openings in their banks into the furrows between rows of cultivated plants or trees or upon grain or meadow fields.

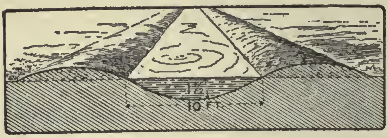


Figure 156. Supply ditch as made with reversible road machine or with plow and scraper, as in Figures 117 and 155.

In constructing this homemade level it may be adjusted to read level by means of a screw arrangement, or even a wedge, to raise or lower one end of the spirit level on the rail, and two stakes 16½ feet apart, driven at first as nearly level as the eye can judge. By repeated trial, by reversing ends and driving down the higher stake, the tops of the stakes can be made the same height and the instrument adjusted to read level. The extension leg at one end can then be lowered according to the grade to be given the ditch, as follows: One-eighth inch per rod giving a grade of 40 inches per mile; 2/8, 80 inches; 3/8, 120 inches, or 10 feet, etc., as regulated by the figures on the adjustable leg, shown in Figure 160.

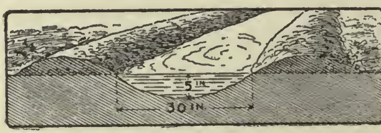


Figure 157. Ditch for farm laterals as plowed out by means of ordinary stubble plow or double moldboard or finished by means of a V-shaped scraper, as in Figure 163.

To mark out a grade for a ditch leading from the supply ditch, place the shorter, stationary, leg at the point of taking in the water; dig a place for the longer, adjustable, leg to a depth at which the bulb will read level. Moving the leveling device forward place the short leg in the last hole and dig another hole sufficiently deep so that when the long leg is placed in it the bulb again reads level. By following a slope requiring holes of nearly equal depth the ditch will be made the desired slant with the minimum amount of excavation and nearly uniform in depth. By means of this biped level the ditch can be carried along that course around a hill which will provide the desired gentle slope, with the ditch made at a uniform depth at all points, thus making it possible to open the ditch out with plows or other cheaply operated machines.

Since it is necessary that field laterals shall be built with embankments so that the surface of the water in them shall rise high enough to flow out on the land when the banks are cut, they must be shallow. On a hillside the earth should all be thrown out on the lower side, but on level or nearly level land it should be

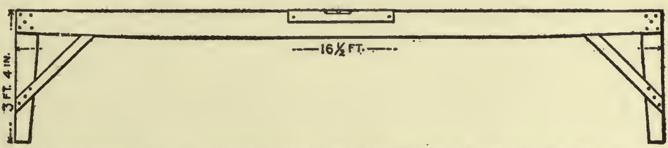


Figure 158. Biped leveling device. See adjustable leg in Figs. 159 and 160.

thrown out on both sides. A double moldboard, or listing plow, as shown in Figure 162, will often make a suitable ditch with once or twice passing. More often some such device as that shown in Figure 163 is necessary to follow the double moldboard plow throwing the earth out on either side, or the single moldboard plow used to throw two or more furrows either side, forming a dead furrow. Where more depth and a larger ditch is required, the "A" can be used to further open out the first dead furrow and a second dead furrow can be thrown out along the same line, again shoving the loosened earth up on the banks by using the "A."

The leveling device shown in Figure 161 can be used in grading the bottoms of ditches. Often water flowing in the ditch can be used to secure the desired slant.

Taking the water from ditches upon the land.—There are various devices for allowing the water to leave the field side ditch and run into the field, and to flood the land from the ditch located within the field. The normal level of running water in the ditch is raised by means of dams made in a variety of ways. In small ditches some spadefuls of earth serve to stop the flow of water, or a part of it, and a small notch cut through the embankment allows a stream of the desired size to flow into the field furrow or to be spread out to flood the land. A canvas dam, fashioned like that shown in Figure 164, and used as in Figure 165, often serves the purpose. A few shovelfuls of earth hold the canvas in place. A dam made like that shown in Figure 166 is often useful.

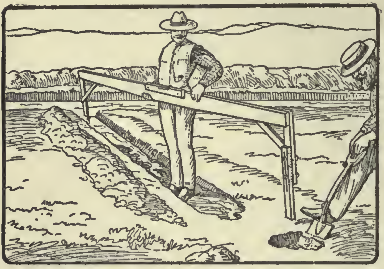


Figure 159. Manner of using biped leveling device

Several dozen pipes made of half-inch boards, with openings 2 x 2 inches and 3 feet long, with gate; or for small amounts of water, four half laths nailed together, and inserted through the bank, with upper end 2 inches below the surface of the water and the outer end leading into the row ditch or into the field, will often enable a man to work more rapidly, and to distribute the water more equitably into furrows or upon the field of grain or grass. The character of the land has much to do with its needs for irrigation, and also with the method which must be employed in the use of the water. Thus, upon sandy or gravelly lands more water is required than on lands

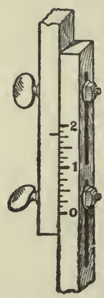


Figure 160. Detail of adjustable leg of biped leveling device.

which will better retain water received from rains or ditches. They become droughty in a moister climate earlier in the spring and sooner after rain. They must be irrigated more frequently than the lands better prepared to conserve moisture. It is difficult on such lands to distribute the water because of the great amount of waste by rapid percolation down below the area reached by the roots of plants and by seepage, and in many cases it is not practicable to use the water on this land, when the same water might be of greater use on lands better adapted to irrigation. Canals made of this kind of sandy and gravelly material are liable to leak large amounts of water, and this is also true of laterals and farm ditches. In some cases it is practicable to place clay in the bottom and along the sides of ditches made of open soil, or to allow them to become coated with sediment from muddy waters that the denser walls thus formed may enable the canal better to retain its water. With some such materials, puddling, i. e., working the clay layer in the ditch when wet, will make it much more retentive. But the greater difficulty in sandy lands lies in getting the water to flow over the field and moisten the surface rather than to sink away immediately and do little good.

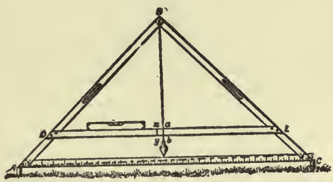


Figure 161. Grade level of light planed boards, made accurately as shown. To establish a 2 per cent grade, for example, bring the instrument to a level along the line of the drain by use of spirit level, F; mark center, a b; then raise the updrain end through a distance one-fiftieth of the length of the base line, A C. The plumb line will cross the board D E, in some line away from the center, a b. Mark this crossing, as x y. The same grade can then be found at any point in the drain by leveling till plumb line crosses at a b, and then raising the updrain end till the plumb line crosses again at x y. A uniform grade can thus be established.

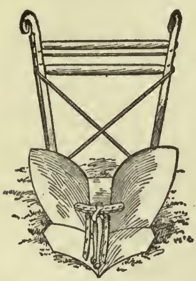


Figure 162. Listing plow, useful in making shallow ditches on level land, as it throws the furrow-slice out on both sides.

Heavy clay soils, on the other hand, serve nicely to carry the water forward in canals and field ditches without serious waste till it is evenly spread over the soil and allowed to percolate slowly downward. On these soils leaching is reduced to a minimum and most of the water supplied is conserved to be taken up by the roots of plants, or is lost by evaporation from the surface of the soil. These heavy soils require intelligent management to make them produce well, whether in a region of heavy rainfall or under irrigation. They are liable to become baked and in poor mechanical condition for producing good crops.

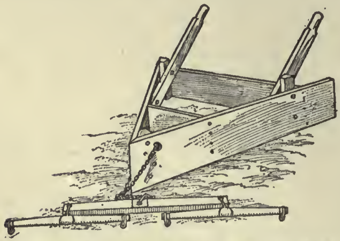


Figure 163. Ditching "A," used for finishing small lateral ditches.

Medium textured soils of mixed sand and clay are best for irrigation, and more money can be profitably invested in irrigating these soils than for the very light or the very heavy soils. The water can be spread over them without great loss; they will absorb and retain large quantities of water and will supply it gradually to the growing crops; they may be cultivated and kept in good mechanical condition without large expense; and they are usually productive.

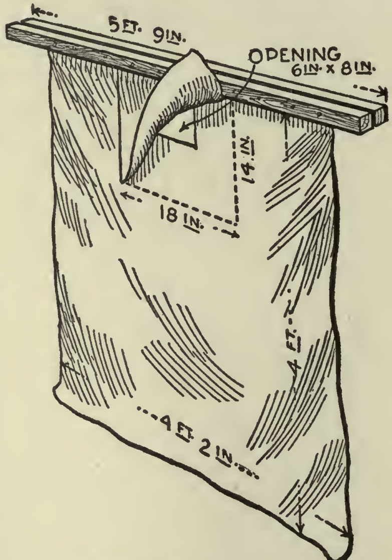


Figure 164. Canvas dam.

Figure 165. Canvas dam in use in a beet field. Lath boxes are shown below the dam in the bank of lateral through which to irrigate each furrow.

Alkaline soils under irrigation must be handled with special care. In many drouthy regions the alkaline soils become still more alkaline when irrigated. This may be due to the water used bringing, in solution, large portions of the alkaline compounds which, upon evaporation, are left in the surface soil. In other cases it is due to the absorption of soluble alkaline compounds from the subsoil by the water, which upon rising to the surface and there evaporating leaves the surface soil with an increased amount of these alkaline substances that are injurious to plants. In yet other cases seepage water from irrigated areas at higher levels absorb large quantities of alkaline compounds and seeping forward through porous underlayers, carry them to the surface on lower areas where the alkaline salts are deposited upon the evaporation of the water. In cases of this kind it sometimes happens that irrigation water applied to one farm

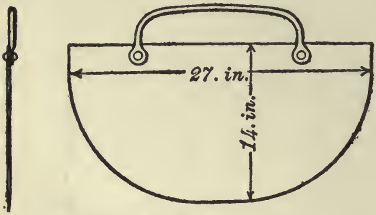
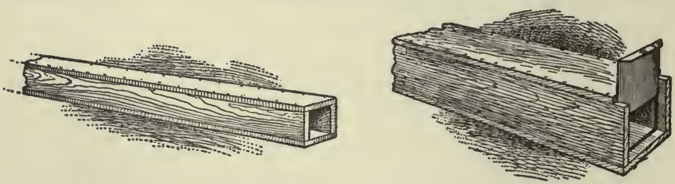


Figure 166. Metal dam or tappoon.



Figures 167 and 168. Small boxes to conduct water from farm ditch into furrows.

will thus flow underneath to another farm and injuriously affect the neighbor's field. In many localities where alkaline soils are irrigated, the conditions must be constantly watched and special care taken not to use more water than is necessary. In this way the fields which might gradually become so alkaline as to be worthless may for a long time be kept suitable for the growth of crops. By using large quantities of water with natural or artificial underdrainage the excess of alkali may be slowly washed out of some soils. In some areas the entire engineering plan for irrigation needs to be arranged with drainage systems so as best to avoid the accumulative injuries of alkali deposited by irrigation or seepage waters.

Crops needing irrigation—All farm, garden and horticultural crops may profitably be irrigated, where water

Figure 169. Turning water from field side ditch into furrows among garden crops.

is inexpensive, at least in dry seasons. Under rare conditions, forest crops may be irrigated profitably. Where water is expensive and the rainfall is sufficient during most years, irrigation can be afforded only for such expensive crops as small fruits and vegetables.

The time of the year in which to apply water to the various crops, is a matter of detail which can be decided only with a knowledge of the local conditions of any crops and of the methods of farm management of any given area. It is often necessary to apply water at or before planting time so that the seeds will germinate and the plants get their roots well developed to enable them to secure water from the subsoil as they mature. In cold regions winter grains should have sufficient water in autumn that they may develop strong roots which will endure the severe conditions of winter. Irrigation in cold latitudes should not be so late as to encourage late maturity of trees, or in case of winter crops as to stimulate too late growth, causing the plants to be in poor condition for winter; better have the ground fairly dry when freezing begins. In some soils the "heaving" of clover and wheat plants from the freezing of the soil is much worse if it is thoroughly saturated with water than if comparatively dry. Grasses, clovers or other perennial or biennial crops should have only sufficient water to enable them to go into the winter with strong, well-matured roots and crowns. In the spring, most cultivated plants need an ample supply of water with which to enable them to start out a vigorous growth. Grass crops are usually benefited by rather large supplies of water frequently applied. Winter and spring cereal grains respond to goodly supplies of water in their earlier growth, and as the period of ripening advances, they do quite as well if given only a medium supply of water. Such luxuriant growers as alfalfa will give an abundant harvest every few weeks if at the time of each mowing they are supplied with several inches of water—an inch meaning sufficient water to cover the surface an inch deep. Indian corn thrives best with a

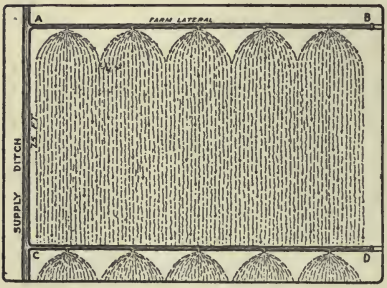


Figure 170. Flooding from field laterals without furrows.

medium amount of water applied throughout its growing season. Being a southern plant adapted to warm, open soils, it does best if not watered too heavily at one time. This is particularly true on soils which are dense and cold. The experience of local growers and the instruction emanating from the agricultural colleges, state experiment stations and the United States Department of Agriculture should be of the greatest value to those who are studying how and when to apply water and the quantities best to use at each application. Extensive studies of when to irrigate each crop, how to apply the water, how much to apply and the manner of after cultivation are being made by the United States Department of Agriculture and by various state experiment stations, and by a letter of inquiry the farmer or teacher can easily find how to secure literature giving these facts.

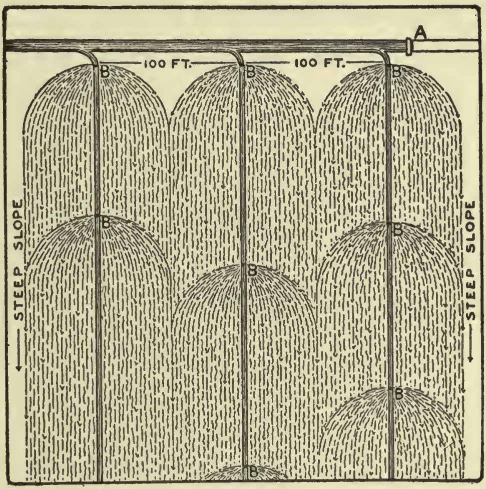


Figure 171. Flooding from ditches running down the slope.

Very often the farmer cannot entirely control the time of application of irrigation water: the needs of other farmers, the priority of rights, the available supply of water in stream or reservoir, and his own convenience in looking after the application of the water in connection with carrying on other work on the farm, all make the problem one which requires constant thought and must be solved at the time with all the facts in mind. Where it is known there will be a scarcity of water for irrigation in midsummer, as in some parts of Oregon and Arizona, the practice of filling the subsoil with water in winter and spring and making this serve as a reserve supply has been largely followed with great success.

The time of day to apply water is relatively of greater moment when applying small amounts, as with the watering pot or sprinkling hose, than where the farmer places several inches of water on a growing crop. Water applied in the morning with the sprinkling pot penetrates only an inch or two into the soil and the hot, dry air of the sunshiny day will evaporate a large portion of it. The same amount of water applied in the evening has a longer time in which to penetrate the soil in response to the force of capillary attraction, and a less amount is left at the surface to be taken up by the atmosphere the following day. But where several inches of water are run upon land from ditches, less attention can be given to the time of day of its application, and, indeed, there is very little difference since the soil is kept wet at the surface for some time while water is slowly percolating downward, under the influence of capillary attraction aided by gravitation.

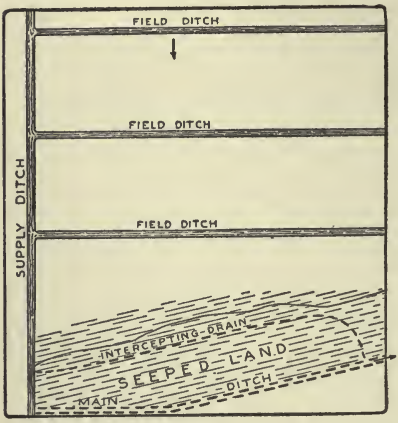


Figure 172. Ditch at the foot of an irrigated field which catches and carries off the seepage water which otherwise would seep into the low area and upon evaporating would leave so much of salts as to make it too alkaline for crops.

Irrigation and special cultivation.—Adjacent fields with or without irrigation require different cultivation. That on which large amounts of water are applied should be plowed deeper, and subsoiling is sometimes necessary in heavy soils, receiving much water. Irrigation tends to make the soil denser, less porous, colder and heavier to handle with tillage implements. In regions so drouthy that irrigation is necessary, lands not irrigated are quite as well managed if they are not plowed so deeply, and they are kept mellow with much less cultivation than is sometimes necessary in lands heavily watered. Among corn and other crops which may be cultivated between the rows, the surface should be broken up with the cultivator as soon after applying the water as the soil is sufficiently dry to be handled. This cultivation prevents the rise of the water to the surface, and conserves it for the use of crops and provides suitable mechanical conditions for the roots of the crops. Coarse and green manures, also artificial fertilizers, are especially profitable where the land can be kept so uniformly moist that it is adapted to the best use of the available fertility.

Subirrigation.—Various forms of subirrigation have been devised. A very simple form is one in which the water is supplied from below, as in greenhouse benches. Supplying water is also accomplished by means of tile drains laid one or more feet below the surface in the fields. Instead of these drains being used to run the water out of the soil, they serve to carry the water into the soil. This method has the advantage of not causing the surface to bake, as in surface irrigation, where dry, bright weather following the application of large quantities of water to a surface of heavy soils causes the surface soil to become baked and hard. This form of irrigation, however, is limited to gardens where valuable crops are grown, and where water is plentiful, or to greenhouses where the water is under full control.

CHAPTER XI

ROADS AND BRIDGES

Prior to 1850 all progressive countries were putting forth great efforts in making common roads. The expense being very large, the work progressed slowly. These roads were needed for the arts of peace and in times of war. Military rulers often found it necessary to use their autocratic powers in constructing permanent roads in times of peace that they might have a means of more rapidly moving their armies and munitions during times of war. The older countries, having been long under these conditions, had succeeded in making substantial roads along many of the principal lines of travel, as between towns, though little had been done for the greater proportion of the mileage of roads among and within farms. Prior to the above date the local communities of the United States, in some cases aided by the state and even by the nation, were bravely struggling to inaugurate a system of good roads. The country was new, the distances great, making the total mileage of wagon roads very large in proportion to the capital invested in farms, or even in proportion to the total capital of the entire country. It looked as though centuries would be required to make a network of good roads throughout this vast country.

Modern road building.—The people looked back to the times when the Romans built great military roads leading from Rome toward different parts of the world. They observed with interest the natural and historical evidences of roadways among some of the ancient people of South America, notably the Incas of Peru. They studied with great interest contemporaneous road building in Europe. They projected and partially completed a great national highway from the Atlantic seaboard westward, finishing it into Indiana. They built roadways between large cities and planned many more. In addition to this, the farmers were making efforts to connect their farms with nearby towns and villages, with the great turnpikes, and with the markets on seaboard, on the larger lakes and on rivers and canals. In many instances, the only means of securing roads was for companies to construct them and charge toll, such companies often securing a bonus from villages and towns. During the first half of the nineteenth century, the improvements of transportation were in three directions; namely, wagon roads, canals and rivers. But about the middle of the century railway transportation began to assume great importance as a practicable feature, and it grew so rapidly that the development in other lines of transportation took minor places. Recently electric roads across the country have also entered the field, and again attention is drawn by the steel track from the wagon road and canal. But this is much more than counteracted by the new vehicles, the bicycle and the automobile, which have helped to awaken a new engineering era in highway building. The improvement of canals, rivers, harbors and water shipping generally has also taken on wonderful activity. Water transportation on lakes and canals, especially, is proving important as a means of cheaply moving such bulky freight as coal, iron, grain, lumber and stone, and in many cases furnishes corrective competition to railway transportation. The intercontinental highway project was abandoned, as were also most of the plans for making superior wagon roads between cities and towns. In half a century several railroads have connected the Atlantic with the Pacific, and many railroads have connected the North and South, while innumerable branch lines and trolley roads have gridironed all the states, connecting cities with cities, cities and lakes with the ocean, and even paralleling canals and rivers. This kind of good roads has been in such great demand by the people that for the time being they were looked upon as the main solution of the road problem. Freight is more cheaply hauled on steel railways than on macadamized roadways. Freight rates have been marvelously reduced. People are able to travel many times faster than on wagon roads,

Figure 173. The road the pioneers traveled.

and at the same time with far less expense, and with much greater comfort and even with greater safety, though the bicycle and the automobile are adding a new importance to the well-made highway. These steel highways have also revolutionized the distribution of mails and made possible the widespread circulation of news and greatly increased the entire activities of the whole people. The competition of railways has forced traffic on waterways into new activity and into developing speed. Especially has ocean transportation received impetus from this new form of steam and electric highways. The world has become as a state and the state as a county in respect to distances or the time required to travel or to transport materials and spread the world's news. Wagon roads, on the other hand, have become only the terminal branches, the capillaries, to the great transportation or circulatory system of the country and the world. The people have been eager for railway

Figure 174. The same road as in Fig. 173, prepared with macadam stone surfacing for a civilization with consolidated rural schools.

accommodations. They have contentedly paid high freight and passenger charges, and railroading has been sufficiently profitable to attract capital so that railroads have been built into all sections of the country, often reaching out far beyond settlements, thus carrying civilization to the wilderness. Towns and counties have voted bonds to attract railways, the contest often running high between towns desiring the location of the new lines. Thus the attention of the people has been directed toward securing the superb system of railway transportation now well advanced toward completion.

Road building must be pushed forward.—While the people have done much during this half century of railway and shipbuilding to build up the country highways, there is need of very much greater energy applied in this direction. A new and mighty movement like that which built up a system of railways is needed and seems to be impending. The people are coming to the conclusion that the farm home and the farm business must not remain walled in by miles of mud. The prosperity accompanying cheap railroad transportation and the consequent enlargement of our cities has given the farmers and the states much larger means with which to build wagon roads; and the people, now that they have the railroad transportation in a nearly satisfactory condition, are showing their readiness to take up the making of wagon roads as a general movement and are pushing their construction forward. While the building of railways was a stupendous undertaking, the construction of high-class wagon roads, generally, over the vast stretches of roadway is even a more difficult problem. In half a century our railways have been developed, but it is questionable if the permanent construction of our highways can be dealt with in so short a time. Many believe that only by the general co-operation of the national government, the state governments, the local government and the farmers can this be brought about, without too serious loss in waiting for facilities the country cannot afford to be without.

Road building has been neglected.—During the period of railway building the making of good wagon roads was left almost entirely to the farming communities, until during the present century. Now state and national movements looking to general co-operation have been started, though not yet generally well organized. The cities, having grown very rapidly, have been occupied in building their own roads, the streets, and their task in that line is only well begun. The government and states, as well as counties and towns, have devoted large subsidies to railways, but, as a rule, the county has until recently been the largest unit to appropriate money for wagon roads. In many cases the whole burden has been left with the township or with the sub-district within the township. Railways have been pushed forward by immense capital aggregated in the hands of corporations or individuals, while the construction of wagon roads has been left to the votes of the people not well organized into co-operative bodies. Capital invested in railways has been profitable to the capitalists, and to the people as well. Money and labor invested in country roads have been valuable to the people, but in a way which has not been fully recognized by the persons doing the work or paying the taxes. The self-interest of the individual farmer has not been sufficient to induce him to do more than his minimum share toward making good roads. The wisdom and the leadership of our largest co-operative units, the state and national governments, have been called for by those directing the movement to secure much more attention to a large and systematic movement in highway improvement.

Investment in good roads pays.—Cases where money has been invested in properly built country roads without the people feeling that the investment has paid, are rare. Our expenditure in country road building has been very much underdone. We could afford to expend annually two to four times as much in bettering our roads, and we can expend it in a far better manner if we will.

Good roads help the farmer.—They increase the farm value of his marketable products. They enable him to market bulky products which he could not market with roads over which he could not easily transport them. They help him by reducing the cost at the farm of purchased products. Better roadways in the neighborhood leading to a village, to the church and to the school, increase the value of the land.

Good roads make life more pleasant on the farm. The business of farming can be done in a more agreeable and less cramped way if there is an easy way of communication with others. Intellectually, life is more pleasant, interesting and elevating if the means of communication with neighbors and with the outside world are made better; if free transportation of pupils is provided, and if mail can be received daily. Socially, farm life is improved by good roads since they lessen the isolation and make visiting between families more frequent; they result in more frequent reciprocal visits with friends in village or city, and aid in building up rural social organization. Churches and co-operative business organizations can be more highly developed, both in rural communities and in villages. Rural delivery of mail is a twentieth-century improvement, the value of which can hardly be compared to any other public service in which the farmers and the nation are interested, and it is made more practicable by improved roads.

Good roads and country life education.—The most important agricultural problem, and the most important educational problem, now up for solution is the pedagogical organization of the splendid practical and scientific body of knowledge concerning farming and home making being accumulated by experiment stations and departments of agriculture, and the development of schools adapted to carrying this knowledge to all farm youth. Here, as in city life education, three grades of schools are being organized—rural schools, agricultural high schools and agricultural colleges—parallel to the city primary schools, city high schools and the colleges of the university. The most important step in this work is the redistricting and consolidating of the rural schools in all regions where good farming lands warrant this increased expense for school facilities. Hauling rural pupils to the consolidated rural school out in the open country and to the village and town school is the most expensive item of this necessary system, and to make it practical and not too expensive the roads must be passable at all times.

Good roads help cities and villages.—By making farming more prosperous, and rural life richer, the resources of villages and cities are increased. The city and country are brought into closer communication. The city needs an easier way of communicating with the country, as well as the country with the city. With good roads the markets of the city are more regularly supplied with foods and other farm products. Business is generally accelerated in the city by being placed in more easy communication with the country. A more active market is provided for manufactured and imported products. Professional and expert services are in greater demand because the farmers can better reach the city, and physicians, artisans and others can more easily serve the country. In villages, especially, business, schools, churches, societies, etc., are better built up since the number of people who can easily reach these smaller centers of population is widened by better roadways. Good country roads make better carriage, bicycle and automobile ways for city people as well as for country people to use and enjoy.

Good roads help transportation companies.—If we could now have the bettered roads which the next half century will see, we would add greatly to the profits of railway and other transportation companies. Products hauled to the railway, canal or river stations would be greatly increased. Farmers could market more of those bulky products which bring more freight receipts.

Besides, they could purchase products of heavier bulk. By enabling farmers and others to get to and from the cities more easily passenger traffic would be increased. With good roads there would be no muddy time in spring or fall when crops could not be marketed, thus congesting traffic at other seasons of the year, and less rolling stock would be needed on railroads for emergencies. As we increase the ability of the farmer to go about among his neighbors and to distant towns and cities, co-operation among farmers and between farmers and corporations becomes more practical and there is less opportunity for friction; there is a closer fellowship everywhere.

Road legislation.—In some respects the making of laws relating to public highways in most American states is decidedly behind the times. Some of the general principles which must be recognized in a public movement for building roads are not found in the laws of most of the states. As a rule, there is no adequate provision contemplated in our laws for the surveying and making of general plans for systems of roads nor detailed engineering plans for their construction. Neither do the laws sufficiently arrange for superintending the construction and maintenance of roadways. The work is too often left to men with very short tenure of office not trained in that phase of engineering which has to do with planning, building or maintaining these important arteries of commerce.

Laws should provide more liberally for educating men in road making and for seeking the best methods of building roads. A detailed knowledge is needed of where good road material is to be found, how secured and how used. Too little is known of the use of different kinds of gravel, stones or other materials useful in road surfacing, and even the nomenclature of materials useful in road surfaces should be better developed. Men educated in road improvement and maintenance are the public's advisers and they should be made responsible for conservative leadership in inaugurating movements for raising the funds and arranging for the construction of improved roadways.

Most encouraging progress is, however, being made. A number of states have highway commissions or bureaus, and the office of public roads of the United States Department of Agriculture is devoted to the development of the science of road work and to giving advice and assistance to road bureaus, to road officers and to private parties in the various states. A class of men trained in road building is being developed, and annually there is progress in laws relating to the improvement of roads. The amount of money being invested in road construction and road maintenance is being increased, though not so rapidly as would be profitable.

Highway funds.—The procuring of funds for the large expense which must necessarily be incurred in the general improvement of our highways is a serious matter. Heretofore in most states the farmers have paid almost the entire expense. This has become so nearly the custom that it has seemed revolutionary to talk of other methods. It has been recognized that the county should pay for large bridges and for special improvements, as macadamizing the principal roadways. It is only recently that public opinion has turned to the states and even to the nation as sources of additional funds for constructing roads, and especially funds for studying out the best plans for making highways, for finding the best materials for road surfaces, for making the necessary surveys preparatory to road building and for superintending the work of constructing roads.

If the state furnishes part of the means with which to improve the roads, she gains the right to assist in superintending the work. Farmers have been loath to give up this right. Some have feared that giving up this right would take away from them the opportunity to earn wages in road construction, and would entail upon them larger expense annually, in road improvements. But since the benefits will be so very much greater than the cost, there seems no general reason for doubt but that a fairly general plan of state aid will, in the end, greatly benefit the farmers and also the state at large. Even the plan for national aid in road building has gained in popularity during the first decade of the century.

The method of taxation.—Whatever money the state provides to aid a locality in building a road may properly come from general state funds. It is quite proper, however, for the state to create special funds for highway improvement. So, in some states, the constitution devotes to its road and bridge fund such funds as accrue from interest on certain investments, as from lands given by the national government to the state for internal improvements. Likewise some assert that the state might properly devote the proceeds of special inheritance taxes or taxes on the income of large transportation, and other corporations.

In most states the county draws upon its current expense fund, or places upon its tax levies a special tax for the construction of bridges and roads to aid townships or localities. In many states the township levies a special property tax, also in some cases a personal tax called a poll tax is levied, to be used in the construction of roads. Formerly the general plan prevailed of giving each man the privilege of paying his poll tax in cash or of working its equivalent out on the roads. Under a more businesslike arrangement of road construction and maintenance, it seems wise to have all taxes paid in money, that the work may be in the hands of superintendents and laborers, who, with experience, become expert in building and caring for roads.

Pike district, as here used, means the legal co-operative organization of the people owning land along or near to the leading road which they desire to have materially improved. Laws can be framed to facilitate the organization of such districts in a way that the first cost of the improvements to be borne locally can be equally distributed over the adjacent and nearby lands which will be greatly benefited by the improved road. The law should also contemplate drawing upon county funds and even state funds to aid communities that are thus situated, and thus provide a co-operative organization—the landowners, the county and the state—which will pay the larger portion of the expense of making a superior road. One of the greatest advantages of a state highway fund is that the state government can use it to induce farmers and even cities and villages to unite in co-operative associations to improve the roads. One of the greatest functions of government is to lead its communities to enter upon larger needed enterprises than they alone would undertake. The opportunity to secure state funds will induce the people of a locality to forget their own differences and unite for the larger objects.

Cities sometimes aid.—In the improvement of roads, state laws should also contemplate requiring aid from cities. In many cases cities pay for part of the roads radiating from their centers, as they are thus placed in better communication with the farm communities; and without laws looking to co-operation between city and country, the city must often do without good roads leading to the surrounding country. Private funds are often used for making roads. It would be quite proper for the laws to recognize parties who will invest money in roads by abating part of their road taxes for a series of years in return for their advancing means with which to build a road in which they are especially interested, but by which the public is also benefited. Care must be taken, in framing this kind of legislation, to prevent abuses, but it would seem quite right to enable a board of county commissioners to make a contract with a landowner under which he might make a much-needed road, with the understanding that he should be for some specified time exempted from a large portion of his road taxes. Requiring the county board to secure the consent of the state highway officers to legalize such contracts with private parties would be an ample safeguard.

Co-operation in road making should be encouraged by the state.—Thus the state, the county, the township, the pike district and the individual should all be brought into co-operation. This principle has not been fully recognized by our law makers. A state highway bureau, with even a small amount of money at its command, and with liberty to use this money to help those who are ready to help themselves—who are anxious to make roads under the best possible plans—does a great deal of good in bringing about co-operation and in developing a far better system of highways. Such a bureau induces counties to co-operate better in building intercity railways. It induces the organization of co-operative pike districts, and aids in finding the best materials for making roads and devising the best plans for construction and maintenance. It advises where to get the best road machinery and aids in selecting road engineers, county engineers and superintendents of road maintenance, capable and honest, who will serve the public well. The office of public roads of the United States Department of Agriculture likewise is of much service, since, with a small fund, it aids in promoting the co-operative construction of the roadways.

Speaking broadly, there are in the United States 2,225,000 miles of public highways. On these there is spent annually approximately $90,000,000, or $1 per capita for the whole people, or $3 per capita for those classes concerned directly with agriculture. Of this sum the larger part is used for maintenance and the smaller part for construction. The cost of construction averages approximately $500 per mile for earth roads, $1,500 for gravel and sand-clay roads and $6,000 for stone, macadam roads.

For the purposes of estimating the cost of further construction, it may be assumed that there are yet to be constructed 10 per cent of the entire mileage, or 225,000 miles of macadam; 30 per cent, or 675,000 of gravel and sand-clay roads; and 40 per cent, or 1,000,000 of earth roads. Using the above figures, the total cost of macadam roads will be $1,350,000,000; of gravel roads, $1,012,500,000, and of earth roads, $500,000,000, or a total of $2,862,500,000. To this may be added an estimate of $187,500,000 for the construction of bridges and permanent culverts, making a total of $3,000,000,000. By making the expenditure for construction alone $100,000,000 annually, this construction work could be completed in 30 years. The more highly developed road surfaces will cause an increase in the cost of maintenance also, but the increase in population will, on the other hand, help to keep down the cost per capita. The increased value of farm lands which will result from the construction of a system of good roads will alone more than justify the expense.

Improved plans for farming; better farm machinery, plants and animals; improved railway and water transportation, rural mail delivery, rural telephones and the greater wealth-producing non-agricultural industries, are all so enormously increasing the country's wealth that there is coming an abundance to draw upon for the needed sums to invest in permanent roadways in rural as well as in urban communities. If the rural communities cannot with sufficient rapidity organize and improve their roads, the state and national governments, in the interest of the whole people, should aid in organizing them. By providing a portion of the money, the larger co-operative unit can purchase the right of the local community to aid in administering road affairs in which the interest of the state and national governments is as clearly defined, though not to the same extent, as the locality.

SURVEYING AND MECHANICAL APPLIANCES

The road engineer requires a special education in civil engineering, in surveying, in devising practical plans and in superintending construction work. Those responsible for the construction of public highways should be more enterprising in employing men trained in planning and superintending construction. The annual loss from plans poorly made is much more than sufficient to pay a sufficient number of highway engineers to place our road building on a scientific basis.

The preliminary survey.—Too many of our highways have been located by persons who were interested in roads accommodating a particular point or person rather than by county or state officials who take into consideration the greatest benefit to the largest number of people at present and in future. The first thing to be considered in locating the line of the road is the preliminary survey, which decides in a broad way the general location of the road, and locates bridges and culverts and determines the cost as compared with other proposed lines. Since the hauling of surfacing materials is often a very expensive operation, consideration should be given to the proximity of materials which will make a good surface for the future finished road.

Locating pioneer roads.—In hilly lands the pioneers locate their roadways along the lines of easiest travel, or along the lines where it requires the least work to make an opening. The road is often made to go around some wet place or to escape a sharp hill. Soon, however, the settlement of the lands and farms results in the road being placed along the straight lines around the "sections," as surveyed a mile square by the national government, or along subdivision lines of the section. Thus it has occurred that the roads of the prairie states follow straight lines, requiring the travel to be around square corners, making longer distances, though on the other hand making the fields of the farmers rectangular and more easily tilled.

In hilly countries it is especially advantageous to have the county board, in pioneer times, select the routes so as to make the grades fairly easy. And it is often necessary, in later years, for the county to straighten the lines at considerable expense. The distance around a hill is often no greater than the distance over it, just as the distance is no greater to follow the bail from one side of a pail to the other, whether it is erect or lies flat on the top of the pail. Ofttimes the heavy grades of a hill can be saved by going little or no further, around or near the foot of the hill. It is not so important in hilly countries to have square fields; in fact, not so practical, as in a gently undulating or level country. Some attention should be given to the ease of making the pioneer road and it is sometimes advisable to make a temporary location, but the general plan should provide for its being straightened out, as means can be afforded. The general plan should be recorded that it may sometime be followed out. The relocation of roads should be done with great care, since the construction of permanent roadways often requires the expenditure of large sums of money.

In swampy countries the roadway should often be located where the combined advantages of having a road and draining the swamp will best serve the united interests of the traveling public and those interested in combining the draining of the adjoining swampy fields with the drainage of the roadway. The road line should be located where the moving of materials needed to cover the roadway in the swampy land will not be too expensive. In the beginning only a few general roads should be made at rather wide intervals across large swampy areas, the cross roads being constructed later on.

Survey for construction.—Once the line of road is determined, and in a general way the depth of the cuts and fills decided upon, there should be a survey for construction. Specifications should be made, even if only cheaply surveyed in cases of light grades, for the depths to excavate each cut and to fill each grade. Likewise, specifications should be made for the kinds of material to use in constructing the surface, the depths to place each layer of surfacing material, and the manner of laying, mixing and packing these layers. Specifications should be made for bridges and culverts. In determining upon the grade many things must be taken into consideration. The rule followed by some railroad engineers that a certain grade, say 20 feet to the mile throughout the entire line, shall not be exceeded, is not quite so important in highway engineering as in railroad construction. Horses drawing a load, or men propelling a bicycle, have stored up energy, which by an extra effort may be utilized in larger amounts for a short time. This enables the horse or bicyclist to mount unusually steep grades if they are not too long. As automobiles come into general use for carriage and freight purposes, and rural electric railways are used, there is greater need of avoiding steep grades in our wagon roads even for short distances. A copy of the profile and of the notes showing the depths at the cross-section stakes should be furnished to the contractor or superintendent of construction.

In cases where much grading is necessary the roadway should be surveyed and stakes placed at either side of the proposed road. On stakes at the sides of the roadway are placed figures showing how deep to cut or how deep to fill at each successive point along the line of the road. Diagrams should also be made showing the width of the road bed and the slope of the banks in cuts and in fills. Frequently the width for the road can be determined only with a knowledge of several factors; the importance of the road and the amount it is used, the means available for its construction, the kind of surfacing material to be applied, and the volume of water to be carried by the ditches beside the road. The slant to be given the banks in cuts, or slope on the sides of the grades in fills, will be determined by the character of the material of the banks. Solid rock may be left vertical, loose sand or running clays must have a very low slant. Ordinary mixed earth of sand and clay requires a slant of 30 to 45 degrees according to its ability to stand. Sometimes fertile soil which will retain moisture may be placed on the surfaces of embankments and planted to grasses, which will prevent them from being washed down by rains.

Specifications for the surface.—While hauling the heavy material for surfacing has become a comparatively simple matter, few road contractors or superintendents understand how to secure the best material for the surface or how to place it on the roadway in the best manner. There is greater need of engineering knowledge and experience at this point than at any other. The available materials are so varied in character and may be combined in so many ways that the plans for making the earth road, the gravel surface, or even the macadam roadway, cannot usually be made in a theoretical or offhand way. In some cases, the most economical and best way for managing the construction of the road surface can be determined only after the grade has been nearly finished. Materials uncovered while excavating cuts, or materials found in outside areas from which earth is secured in constructing the grade, are often best to use alone or in combination with materials brought from outside in making up the road surface.

In some instances it is best to give the contractor, and the superintendent (representing the public) who daily inspects the work, some latitude, stating the specifications for the construction of a road surface of a given quality and character in general, yet binding, terms.

In giving the contract for the formation of the grade or substructure, it can be specified that the best materials for subsurfacing found within the cuts be spread on top of the substructure as a foundation upon which the surfacing materials are to be laid. Thus, by using gravel from cuts, such a well-drained solid top can be put on the substructure that the superstructure need not be made so thick nor so expensive as if such poor materials as soft clay were left at the top, or if the upper part of the substructure were made up of alternating patches of soft clay, coarse gravel, sand, or sand and clay mixed, giving a foundation variable in rigidity and uneven in its capacity for removing water from the superstructure or for allowing surface water to percolate through it.

Where the surface is to be made of macadam, brick or other hard substance, and something is known of the availability of sand or gravel desired as foundation under these surfacing materials, the specifications are easily written.

NOTES BY MAURICE O. ELDRIDGE

COST DATA

It is impossible to fix a price at which certain types of roads can be built. A macadam road which may be constructed in one part of the country for three thousand dollars per mile cannot be duplicated in another part of the country for less than ten thousand dollars per mile. The cost of roads varies with cost of labor, teams and materials, the distance the materials are hauled, amount of grading done, etc. On some roads the grading will cost as much as all of the other items entering into the cost of the road, while on another road of the same type there may be no rough grading at all. The cost of labor on roads varies all the way from seventy-five cents to two dollars per day in the different parts of the country. In many places materials can be secured gratis, but in others they have to be paid for by the ton or cubic yard. Suitable materials are frequently found immediately adjacent to the road to be made, but in many instances, materials have to be brought long distances by rail or boat.

The rates charged for hauling road materials by the railroads in some of the middle western states are given below. The rate given for Iowa is the same as that charged for soft or slack coal, which is the lowest rate given for any material.

Railroad Rates on Road Materials

Rate per 2000 pounds

Miles	Missouri	Illinois	Iowa	So. Dak.	Minn.
25	$1.00	$0.80	$0.37	$0.90	$0.80
50	1.20	.98 2-10	.52	1.20	1.20
75	1.40	1.13 4-10	.64	1.40	1.40
100	1.60	1.26 8-10	.74	1.60	1.60
200	2.40	1.69 2-10	1.04	2.50	2.40
300	3.00	1.99	1.24	3.10	3.00

The cost of hauling rock from the crusher or the railroad station to the road, measured one way, is usually about twenty-five cents per cubic yard per mile. If the rock is being hauled from bins where the stone is loaded into wagons automatically, about seven or eight cents per cubic yard should be added to the total cost of hauling for loading and unloading, lost time, etc. If the rock is hauled from the railroad station, about fifteen cents per cubic yard should be added for loading and unloading, lost time, etc.

A wide difference in the cost of roads is shown by the following table, which gives the total cost of roads constructed under the direction of the Office of Public Roads of the United States Department of Agriculture in several different states during the year 1904-05.

Cost of object-lesson roads built in 1904-5

Place	Material for Surfacing	Source of Material	Wages per day	Dimensions of Road Length, ft.	Width, ft.	Depth, in.	Total	Cost of Road Per sq. yd.	Per Mile
Fernandina, Fla.	Shells	Local	$1.00	1,199	24	6	$1,113.85	$0.348	$4,899.84
Pensacola, Fla.	Granite & trap	Balast, Germany	1.25	506	32	6	419.50	.429	8,053.76
Jacksonville, Fla.	Marl	By rail 250 miles	1.25	5,280	15	6	5,211.03	.592	5,211.03
Neosho, Mo.	Novaculite	Local	1.00	2,640	12	7	1,529.11	.434	a3,055.36
Beaumont, Tex.	Clam shells	By boat 28 miles	....	3,154	16	7	......	1.019	b9,565.01
Tallahassee, Fla.	Sand-clay	Local	1.00	4,480	16	7½	440.00	.055	516.27
Pensacola, Fla.	Sand-clay	Local	....	1,800	15	8	419.50	.140	c1,232.00
Gainesville, Fla.	Flint	By wagon 6 miles	1.00	265	70	8	572.31	.278	11,416.53
Shreveport, La.	Gravel	By rail 32 miles	1.00	3,306	16	8	1,962.28	.334	3,135.15
Walla Walla, Wash.	Trap	By rail 13 miles	1.50	2,048	18	8	1,701.84	.415	4,382.40
Bellingham, Wash.	Granite	By rail 30 miles	2.00	2,050	15	8	2,683.86	.785	6,908.00
DeKalb, Ill.	Limestone	By rail 100 miles	1.75	4,510	12	8	5,920.42	.985	6,934.40
Gainesville, Fla.	Sand-clay	Local	1.00	5,280	14	9	881.25	.107	881.25
Springfield, Mo.	Novaculite	By wagon 2½ miles	1.00	1,310	16	9	780.00	.335	3,144.53
Arkansas City, Kans.	Limestone	Local	1.50	3,615	14	10	2,223.98	.396	3,252.48
Chagrin Falls, Ohio	Sandstone & granite	Local	1.50	2,400	10	10	....	.800	4,693.33
Columbus, Ohio	Brick-granite	Local	1.50	835	18	10	1,629.64	.976	d10,306.56
Lebanon, Mo.	Novaculite	Local	1.00	2,950	9	11	987.00	.335	e1,768.80
Clarksdale, Miss.	Burned clay	On road	1.25	300	12	..	83.95	.210	1,478.40

a $408.25 for culverts.
b Labor, city and county prisoners. Cost was for material only at $2.15 per cubic yard.
c Convict labor used.
d Brick from burned building were crushed and rolled for foundation. Bowlders from fields for surface.
e Novaculite from fields.

The greatest difference in the cost per mile of the roads of similar construction is due to the width, one of the roads being 24, another 32, and one, practically a street, 70 feet in width. On account of the fact that no charge was made for supervision, or for machinery, the cost of these roads was probably from fifteen to twenty-five per cent lower than would be the case in ordinary practice.

UNIT COST OF OBJECT-LESSON MACADAM ROAD, SPRINGFIELD, MO.

The unit cost of the road built under the direction of the Office of Public Roads at Springfield, Missouri, during the year 1904, is given in the following table, and will serve as a type of what can be done in many localities, as the material of which this road was constructed is found in many parts of that region:

	Total cost per day	Cost per cubic yard
Crushing:		
Average daily output 75 cu. yds.		
4 men loading wheelbarrows and feeding crusher, at $1.50 per day	$6.00	.08
5 men operating wheelbarrows at $1.00 per day	5.00	.066
1 crusher attendant	1.50	.02
Water wagon ½ time, at $3.00 per day	1.50	.02
Fuel oil, etc., for engine	2.50	.033
Total	$16.50	.219
Hauling:		
Distance of 2 miles.		
This was done by contract at a cost of 40 cents		.40
Preparing subgrade:		
A regular set of men and teams was employed in this work. The charge is therefore made as for crushing and spreading, as they prepared the subgrade for about 75 cubic yards each day.		
2 teams, at $3.00 per day	$6.00	.08
4 men, at $1.50 per day	6.00	.08
Total	$12.00	.16
Spreading stone and binder:		
6 spreaders at $1.50 per day	$9.00	.12
1 team at $3.00 per day hauling gravel for binder	3.00	.04
Total	$12.00	.16

Rolling and Sprinkling:

Fuel oil, etc.	2.50	.033
Night watchman	1.50	.02
Team ¼ of the time, at $3.00 per day	.75	.01
Total	$4.75	.063

Summary:

Crushing, average daily output 75 cu. yds.	$16.50	.219
Preparing subgrade	12.00	.16
Hauling stone		.40
Spreading stone and binder	12.00	.16
Rolling and sprinkling	4.75	.063
Total	$45.25	1.002

As loose material 9 inches in depth were used, the cost per square yard was therefore about 25 cents. The total amount of material used in the road was 672 cubic yards, and the total cost was $780.00. It will be noticed that 672 cubic yards at $1.00 per cubic yard would amount to $672.00, leaving a little more than $100 for culvert pipe and construction of culverts, repairs to tools and machinery and for incidentals. The cost of this work was probably 15 per cent. lower than would be the case in ordinary practice, as the machinery, expert operators and superintendence were furnished free by the Government.

It will be noticed that no charge was made for piling material at the crusher. This was on account of the fact that the material was furnished free already piled; for, in order to cultivate their crops, the farmers had found it necessary thus to dispose of the rock found in the fields. This fact, however, could not have materially affected the cost of the road, as similar material could have been secured nearer the work, but as it would have been necessary to pick up the rock from the fields, the cost of picking, piling and hauling would have amounted to about the same.

Taking the culverts and incidentals into consideration, this road cost about 35 cents per square yard, or at the rate of $3,285 per mile for a 16-foot road, which is considered a very reasonable cost for first-class work. It would be safe to say, therefore, that roads built under practically the same conditions even after adding the necessary cost of expert supervision, interest and depreciation on plant, can be constructed for about 38 to 40 cents per square yard, or at the rate of $3,750 per mile for 16-foot roadway.

The cost of the road at Springfield, Mo., should not be accepted as a standard for the whole country, for the following reasons: First: Ordinarily there would be a charge for quarrying stone of from 15 to 25 cents per cubic yard; the average for the whole country would probably be 20 cents per cubic yard. This item alone would increase the cost given above 5 cents per square yard. Second: The cost of rough grading, which varies between wide limits in different parts of the country, would also have to be added. Third: The cost of hauling materials would in many cases be from 5 to 8 cents more per cubic yard than was charged at Springfield, and the length of haul might be greater or less. Fourth: If material is brought in by rail or boat the cost of transportation per cubic yard should be added. Fifth: The cost of spreading stone, given above, was much higher than it should be on account of the fact that hand labor was employed. For spreading screenings by hand the cost should be about 16 cents per cubic yard, as given; but stone and gravel can be spread with automatic carts or road graders, and leveled by hand for from 2 to 5 cents per cubic yard. Sixth: Cost of rolling, given above, is low on account of the fact that the material was very readily compacted. The cost for rolling stone varies in different places from 15 to 30 cents per cubic yard, averaging about 25 cents, which is equivalent to 6¼ cents per square yard for a 9-inch road.

COST OF SAND-CLAY ROADS

It is, of course, impossible to state definitely the cost of this form of construction, as it will be found to vary with the price of labor, the length of haul, the width of roadway and depth of material. If we assume, however, that the clay can be procured within a mile of the *sandy roadway* which is to be improved, and that the cost of labor is about $1 and teams $3 per day, the cost of constructing a twelve-foot sand-clay roadway on a sand foundation, covered with clay to an average depth of 6 inches, would be approximately as follows:

	Cost per mile
Crowning and shaping road with road machine, estimated on basis of two teams for one day at $3, and one operator at $1.50	$7.50
Hauling clay, 1760 cubic yards, at 25 cents	440.00
Spreading clay with road machine, estimated on basis for three days, two teams at $3 per day, and operator at $1.50 per day	22.50
Shoveling sand on clay, estimated on basis of ½ cent per square yard	35.20
Plowing, estimated on basis of four days for one team at $3 per day	12.00
Harrowing, estimated on basis of two days for one team at $3	6.00
Shaping and dressing with road machine, estimated on basis of two days, two teams, at $3, and expert operator at $1.50 per day	15.00
Rolling, estimated at ½ cent per square yard	35.20
Total	$573.40

The estimated cost per square yard, therefore, when computed on the basis of this table, would be about 8 cents, or at the rate of $573.40 per mile.

The cost of building a sand-clay road on a *clay foundation* would not vary much from the figures given above. The latter form of construction would probably be slightly cheaper by reason of the fact that sand can be more economically handled than clay.

The cost of sand-clay construction in the south has been found to vary from $200 to $1,200 per mile, in most cases running from $300 to $800. A sand-clay road constructed under the direction of the Office of Public Roads, at Gainesville, Fla., 1 mile in length, 14 feet wide, and having a 9-inch sand-clay surface, cost $881.25 per mile, or 10 cents per square yard. Another sand-clay road, built under the direction of the Office at Tallahassee, Fla., 16 feet wide and surfaced with about seven inches of sand-clay mixture, cost $470 per mile, or about 5 cents per square yard. In case changes of grade have to be made with consequent cuts and fills, the cost would be proportionately greater than the figures given above.

COST OF GRADING

In making plans and specifications for a road, the cost of relocation or the cost of grading the old road will have to be considered. The amount of earth to be moved should be determined by the engineer in charge and the approximate cost per square yard ascertained on a basis of length of haul, kind of material to be moved and cost of loading and unloading.

If the drag or slush scraper is to be used (average capacity ⅛ cubic yard) the average cost of moving earth, according to Gillette, would be about 4½ cents per cubic yard per 100 feet. To this cost Gillette adds 6½ cents per cubic yard for loading and unloading, plowing, etc. According to this estimate the cost for moving earth, say 300 feet with drag scrapers, would be about 20 cents per cubic yard.

Where No. 2 wheel scrapers are to be used (capacity about ¼ of a cubic yard), the cost, according to Gillette, would be about 2½ cents per cubic yard per 100 feet. To this cost he adds 6½ cents per cubic yard for loading and unloading, plowing, etc., For moving earth 300 feet with No. 2 wheel scrapers, the cost would, therefore be about 13 cents per cubic yard.

The cost of moving earth by wagon when the average load is 1 cubic yard, is given by Gillette, as ½ cent per cubic yard per 100 feet, wages of man and team being estimated on the basis of 35 cents per hour. To this he adds a fixed charge of 13 cents per cubic yard for loading, and 5 cents per cubic yard for plowing. The cost for moving earth on this basis, by wagons, would be 19½ cents per cubic yard for 300 feet; or 28 cents per cubic yard per mile.

COST OF ROADS OF VARIOUS WIDTHS

The cost of roads varies not only with the depth of material used, but also with the width. The following note of explanation and tables regarding the number of square yards in a mile of road of different widths and the cost of roads of different widths at a given price per square yard are quoted from the Report of the Commissioner of Public Roads of New Jersey:

"Any variations from the prices given can be quickly ascertained by adding, subtracting, multiplying and dividing for a less or greater width. For example, a road 8 feet wide has 4,693⅓ square yards in 1 mile. To obtain the number of square yards in a road having a width of 9 feet, add ⅛ to the foregoing figures, and in one having a width of 7 feet, subtract ⅛; in one of twice the width given in the table multiply by 2."

Square yards in one mile of road.

8 feet in width	4,693 1-3	sq. yds.
10 "	5,866 2-3	"
12 "	7,040	"
14 "	8,213 1-3	"
16 "	9,386 2-3	"
18 "	10,560	"

Number of square yards and cost per mile for different widths and various prices per square yard.

Width in feet	Number sq. yds.	Cost per sq. yd	Cost per mile
8	4,693 1-3	$0.25	$1,173.33 1-3
10	5,866 2-3	.25	1,466.66 2-3
12	7,040	.25	1,760.00
14	8,213 1-3	.25	2,053.33 1-3
16	9,396 2-3	.25	2,346.66 2-3
18	10,560.	.25	2,640.00
8	4,693 1-3	.30	1,408.00
10	5,866 2-3	.30	1,760.00
12	7,040	.30	2,112.00
14	8,213 1-3	.30	2,464.00
16	9,386 2-3	.30	2,816.00
18	10,560	.30	3,168.00
8	4,693 1-3	.35	1,642.66 2-3
10	5,866 2-3	.35	2,053.33 1-3
12	7,040	.35	2,464.00
14	8,213 1-3	.35	2,874.66 2-3
16	9,386 2-3	.35	3,285.33 1-3
18	10,560	.35	3,696.00
8	4,693 1-3	.40	1,877.33 1-3
10	5,866 2-3	.40	2,346.66 2-3
12	7,040	.40	2,816.00
14	8,231 1-3	.40	3,285.33 1-3

Number of square yards and cost per mile for different widths and various prices per square yard.—Continued.

Width in feet	Number sq. yds.	Cost per sq. yd.	Cost per mile
16	9,386 2-3	.40	3,754.66 2-3
18	10,560	.40	4,224.00
8	9,693 1-3	.45	2,112.00
10	5,866 2-3	.45	2,640.00
12	7,040	.45	3,168.00
14	8,213 1-3	.45	3,696.00
16	9,386 2-3	.45	4,224.00
18	10,560	.45	4,752.00
8	4,693 1-3	.50	2,346.66 2-3
10	5,866 2-3	.50	2,933.33 1-3
12	7,040	.50	3,520.00
14	8,213 1-3	.50	4,106.66 2-3
16	9,386 2-3	.50	4,693.33 1-3
18	10,560	.50	5,280.00
8	4,693 1-3	.60	2,816.00
10	5,866 2-3	.60	3,520.00
12	7,040	.60	4,224.00
14	8,213 1-3	.60	4,928.00
16	9,386 2-3	.60	5,632.00
18	10,560	.60	6,336.00
8	4,693 1-3	.65	3,050.66 2-3
10	5,866 2-3	.65	3,813.33 1-3
12	7,040	.65	4,576.00
14	8,213 1-3	.65	5,338.66 2-3
16	9,386 2-3	.65	6,101.33 1-3
18	10,560	.65	6,864.00
8	4,693 1-3	.70	3,285.33 1-3
10	5,866 2-3	.70	4,106.66 2-3
12	7,040	.70	4,928.00
14	8,213 1-3	.70	5,749.33 1-3
16	9,386 2-3	.70	6,570.66 2-3
18	10,560	.70	7,392.00
8	4,693 1-3	.75	3,520.00
10	5,866 2-3	.75	4,400.00
12	7,040	.75	5,280.00
14	8,213 1-3	.75	6,160.00
16	9,386 2-3	.75	7,040.00
18	10,560	.75	7,920.00
8	4,693 1-3	.80	3,754.66 2-3
10	5,866 2-3	.80	4,693.33 1-3
12	7,040	.80	5,632.00

Number of square yards and cost per mile for different widths and various prices per square yard—Continued

Width in feet	Number sq. yds.	Cost per sq. yd.	Cost per mile
14	8,213 1-3	.80	6,570.66 2-3
16	9,386 2-3	.80	7,509.33 1-3
18	10,560	.80	8,448.00
8	4,693 1-3	.85	3,989.33 1-3
10	5,866 2-3	.85	4,986.66 2-3
12	7,040	.85	5,984.00
14	8,213 1-3	.85	6,981.33 1-3
16	9,386 2-3	.85	7,978.66 2-3
18	10,560	.85	8,976.00
8	4,693 1-3	.90	4,224.00
10	5,866 2-3	.90	5,280.00
12	7,040	.90	6,336.00
14	8,213 1-3	.90	7,392.00
16	9,386 2-3	.60	8,448.00
18	10,560	.60	9,504.00
8	4,693 1-3	.95	4,458.66 2-3
10	5,866 2-3	.95	5,573.33 1-3
12	7,040	.95	6,688.00
14	8,213 1-3	.95	7,802.66 2-3
16	9,386 2-3	.95	8,917.33 -13
18	10,560	.95	10,032.00
8	4,693 1-3	1.00	4,693.33 1-3
10	5,866 2-3	1.00	5,866.66 2-3
12	7,040	1.00	7,040.00
14	8,213 1-3	1.00	8,213.33 1-3
16	9,386 2-3	1.00	9,386.66 2-3
18	10,560	1.00	10,560.00

Where the road is to be covered with gravel, or with a mixture of gravel, sand and clay, or with other forms of materials which are not very hard nor especially prepared, a great deal of common sense must be used in writing specifications and in following them. It is usually better to express the plan in terms somewhat general, but to make the requirements rigid as to securing the very best roadbed practicable under conditions which may develop as the work nears completion, and then have the work done under a competent superintendent. Each new road undertaken brings up new problems.

The road engineer, or person who has charge of public highways, must have a sense of careful discrimination that he may not make a plan so expensive that the people will never carry it out. But, taking all things into consideration, he should make a plan, which, when followed out, will give the most permanent road which it is practical under all the circumstances to build and pay for.

Bridges and culverts.—It is outside the scope of this book to discuss the intricate problems of general bridge engineering. The effort is rather to educate farmers in the lines which they often must manage unaided, leaving the planning and construction of expensive steel, stone, cement and complicated wooden bridges to bridge engineers and to bridge-constructing companies. Extensive observation and experience warrant some general advice to those made responsible for the giving of contracts for public bridges. County commissioners sometimes make the mistake of deciding upon the size of a bridge needed over a given stream without having first secured all the facts. Thus numerous bridges have been built too low and with insufficient room allowed between the abutments, or the abutments have not been sufficiently well built to withstand the strain of the occasional excessive flood. It pays the board which is responsible for the bridge to employ a competent engineer who knows how to secure the facts as to the probable height and force of flood water and how to estimate the height, width and strength of the structure necessary to meet the con-

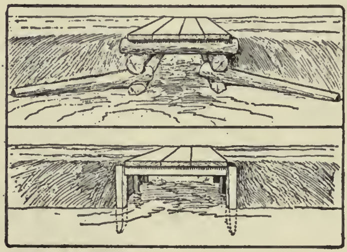


Figure 175. Pioneer wooden culverts are being rapidly supplanted by stone and cement.

ditions. It is not always necessary to make a plan for the bridge, as the representative of each of the competing bridge-building firms may be willing to submit a plan for such a structure as his establishment is qualified to erect and deems best for the purpose. Such plans can be referred to some authority on bridge structures as well as to the resident engineer. Competing firms will use care to have their plans well made if they are required to submit their plans to well-known experts.

In the construction of culverts and small bridge structures permanency is a very important element. The wooden culverts of the pioneer community should be replaced as rapidly as possible with iron pipes, sewer pipes, stone archways, cement structures, concrete reinforced with iron, or with small bridges of a combination of iron, cement, stone and wood. All these forms of bridges are comparatively expensive and cannot be afforded in the early days of the community. It is not wise to undertake to reconstruct all the bridges of a district at once, but by making a few permanent structures each year the county or township will eventually have the waterways beneath its roads made of such enduring materials that their reconstruction every few years, necessary where wood was used, will be a thing of the past.

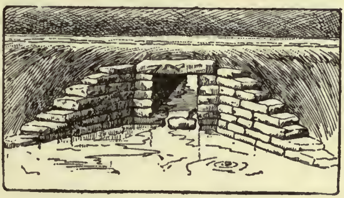


Figure 176. Stone culvert.

Concrete culverts.—The following statement by Hon. Thomas McDonald, of the Iowa highway commission, gives some explicit directions for making culverts. As a rule, it is wise to purchase forms of reinforcing bars manufactured especially for that purpose.

" Unless the cost of concrete materials is very cheap, and unless the haul is short, the flat top form of construction will prove more economical than the arch top for culverts. Less concrete is required, not only in the top, but in the sides. The forms are simpler to build, and the cost of labor is usually lessened.

"In the construction of the flat top culverts it is necessary to use in the tops about 1 per cent of steel in the form of steel rods, bars, old railroad rails, beams, or the patented forms of reinforcing bars.

"The forms will generally be built of 2-inch lumber surfaced on one side with tight joints to prevent escape of the mortar. These will be reinforced at intervals of 2 to 3 feet with 2 x 4's. The weight of concrete tamped into place is so great that unless the forms are built rigid they will bend or break under the load, and an unsightly job will be produced. These forms should be left in place about two weeks at least and for culverts 10 or 12 feet wide a longer time.

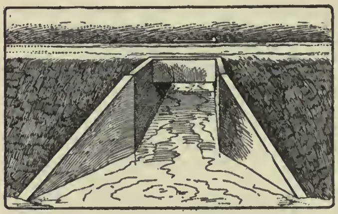


Figure 177. Cement culvert with wing-walls.

"A very much better grade of concrete can be made out of cement, sand, and broken stone than with the sand and cement, and the proportions used would be: *one part cement, three parts sand, and six parts of the broken stone* for the sides, wing walls, bottom and foundations of the culverts, and *one part cement, two parts sand, and four parts of the broken stone* for the top.

"The rods should be embedded in the concrete very close to the under side of the top and near the inside of the side walls. For a culvert with a 4-foot clear span the following dimensions are recommended: Thickness of top 8 inches, reinforced with ¾-inch corrugated bars, spaced 8 inches center to center. If the sides are 4 feet high above the foundation they should be 6 inches thick and reinforced with ¾-inch corrugated bars, about 20 inches center to center. If plain bars are used a somewhat larger per cent of reinforcement should be used.

"For a yard of concrete in the proportions *one, three, six* there will be required 1.11 barrels of cement, 0.47 cubic yards of sand, and 0.94 cubic yards of stone. At the prices given the materials alone for a yard of concrete would be in the neighborhood of $3.50, not including the hauling or mixing. For the *one, two, four* concrete 1.57 barrels of cement will be required, 0.44 cubic yards of sand, and 0.88 cubic yards of broken stone.

"The forms, which are always a costly part of small culverts, should be designed so that they can be used a number of times without wasting the lumber.

"The shape of the culvert is exactly like a square box with the ends knocked out, and it may or may not have a floor. If it does not, the side walls should be carried down to a good foundation. All culverts should have wing walls built at the ends projecting at an angle of about 30 degrees."

PHYSICS OF ROADS

By referring to the discussion of the movement of the water in the soil the reader will understand some of the physical problems in road drainage. In nearly all cases, water softens the road, though in some cases, as in sand, it assists in making the road surface compact. The principles involved in farm drainage apply in a general way to the drainage of a roadbed. Where a roadbed is filled with standing ground water, it is more difficult to keep it solid than where it is well drained, and even an excess of capillary water in and near the surface makes most roadways less solid and less durable.

It is an advantage to have the roadbed shed the rain to the roadside ditch, not allowing it to penetrate into the subsoil. And when the water does enter the surface the substructure is better if constituted of sand gravel or stones, so that it will allow the water to percolate freely downward or to seep off sideways through the open layers of the material of the roadbed Or it should be underdrained in such a manner that the ground water will sink to at least a few feet below the surface. The upper part of the substructure can sometimes be made of coarse material, through which the water can seep sideways, even though the lower part of the grade is made of impervious clay.

Figure 178. A, wheel on hard surface; B, wheel on soft, yielding surface.

Puddling is a character peculiar to soils made up largely of clay. They become soft and mushy when wet, but if thoroughly mixed and worked up while wet, they do not allow water to pass through them. If puddled soils are dried rapidly they become hard and brittle. Thus, the roadway is often cut up into ruts by the wheels of vehicles and the tramping of horses; depressions in these puddled places retain water as does a dish, and when these become dry the road is made very rough by the hard clods of earth. In some cases, these soils become softened again when soaked with rain, though with some soils the clods remain hard for an extended time. Materials which become soft when wet, even though they are hard when dry, are very poorly suited for road surfaces. These clays are sometimes useful to mix with gravels or even with sand to help combine the coarser materials into a surface which will not be soft in wet weather nor too easily crumbled when dry. Puddling is caused by a readjustment of the particles of the clay when wet. The cementing materials harden, holding together the particles of soil, as lime hardens and cements together the particles of sand in mortar. Some of this cement is needed in loose sands or gravels to bind them together in making a firm road surface, since they are too loosely knit together.

Properties of surfacing materials.—That part of the roadway which receives the weight of the passing vehicles and teams, to best serve its purpose, must have a number of qualities of which *solidity* is the first requisite. It must be so solid that the heavy loads will not break it down and thus crumble the crust which is designed to lie intact upon the substructure of the roadway. Thus, a thin hard surface might not have under it a solid basis and it might be crushed into the soft earth beneath it. In Figure 180 is shown how mixed sand and gravel over a peaty soil, unless a foot thick, will be shoved into the soft peat below. A road surface made of macadam or telford, if sufficiently thick, will not be crushed into the substructure, even if soft clay underlies, though with a solid substructure a thinner layer will suffice.

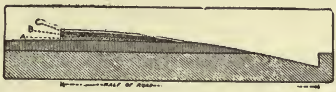


Figure 179. Cross-section of macadam road. A, lower layer of 6 or more inches of 2 to 3-inch stone; B, middle layer of 1 to 2-inch stone; C, layer of broken stone under 1 inch, dust, etc.

Resistance to traction.—A surface is desired which is hard and smooth at the top, that the wheels of vehicles may not sink in and be constantly required to climb over or displace an obstruction as if climbing up a hill. As we require the best steel in the edge of an ax, so we require the hardest, toughest material to endure the wear at the surface of the road. (See Figure 177.)

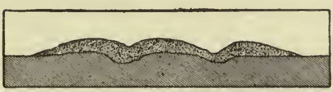


Figure 180. Roadway made of 8 inches of gravel on peat, which the wheels soon punch into the soft muck.

Durability.—Not only is it expensive to make permanent grades, but road surfaces are costly, especially if they must be often renewed. Thus, in making a macadam road, as in Figure 179, limestone is suitable for the lower two-thirds of the bed of stone, but harder rock, as trap rock or granite, on the surface will longer endure the wearing of wheels and teams. Some kinds of gravel, likewise, are very much more valuable for the upper few inches of surface than are other kinds. Gravel made up of granite and trap rock will wear very much longer than gravels composed of limestone or other soft stones. Bricks differ in hardness and durability. Paving brick made in certain localities have proven so superior over the brick made in many other localities that they are shipped hundreds of miles for street and road paving.

Figure 181. Roadside ditches with vertical outer edges.

Ease of repairing is also an important property of the road surface. In this connection, attention must be given in the selection of material for surfacing the road to the ease of getting material for repairs. Materials for construction brought long distances at much expense are sometimes doubly expensive for repairing if the same material must be brought at a disadvantage. There are sometimes less suitable materials near at hand which can easily be secured for renewing broken surfaces and in the end are more practical for the original construction than are the somewhat better kinds which must be brought long distances.

Figure 182. In throwing earth from roadside ditch to the center of the roadway with the reversible road machine the operator can make a ditch with vertical outer bank, leaving the ditch and earth as shown by the line A D; slanting outer banks, as at B F; or rounded bank, as at C E.

THE ROADBED

Draining the roadbed.—Almost any kind of material, except loose gravel or sand or soft peat, will make a hard road under a roof which keeps off the rain. On the other hand, no material except rock or other very hard substance will make a satisfactory road surface if it is kept constantly wet by rain or by ground water. Water which falls upon the roadbed should be conducted sideways into the roadside ditch by having the roadways slope from the center to the sides. The water flowing from the surface of the road to the side ditch, and flood water flowing from adjacent lands upon the roadway, should be taken care of by ample ditches. Where ground water rises within a few feet of the surface beneath roads it should be carried off by means of tile drains. Figures 181 to 189 illustrate roadside ditches of various forms. In Figure 181 is shown the earth road as rounded up with the reversible road machine. The ditches being beside fences, their outer banks are often left vertical. The reversible machine can be so adjusted that both slanting and rounded ditches can be made as shown in Figures 182, 183 and 184. Where the slush or drag scraper is used to make roadside ditches they are left in awkward form, as shown in Figure 185. In many cases the reversible machine can be used to finish the road and ditches thus made, leaving them much in the form shown in Figure 181. (See also Figure 207.) At Figure 187 is shown a cross-section of a large drainage

Figure 183. Rounded ditches.

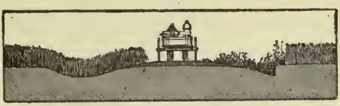


Figure 184. Roadway with rounded ditch on left side and neat crop growing nearly to the wheel tracks. On right side the ditch has a steep bank. Outside the bank and between the bank and the wheel track are areas uncouth with large weeds.

canal on one side of a roadway, the earth excavated from the canal having been used for the roadbed. At Figure 188 is shown a hillside road improperly made, in which the water flowing from the upper side of the hill enters the road and follows down the wheel tracks, washing out a ditch in the center of the roadway. In Figure 189 this same road is shown with ditch on the upper side, paved with cobblestone or other material which will not be displaced by the running water. It is sometimes necessary at short intervals down the hill to have the ditch from the upper side of the road cross the crown of the road to carry the water across the roadway, as in Figure 190. By this means the water accumulating in the ditch on the upper side of the roadbed is carried across and discharged on the lower side, thus avoiding a large ditch, which would be necessary to carry the water accumulating along the upper side of the roadbed on a long hillside. In case of very important roadways, where these cross drains would be objectionable because of making uneven places in the line of the grade, the water may be carried across the road by means of sewer or drain tiles used as sewers to carry the water beneath the crown of the road, as in Figure 191. Figure 192 shows a tile drain under the center of the roadway, and Figure 193 a tile drain under each roadside ditch. Figure 194 shows a

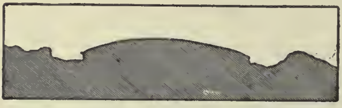


Figure 185. Awkward roadside ditches made with drag or slush scraper.

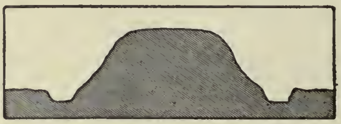


Figure 186. Rude ditches on both sides of a high fill.

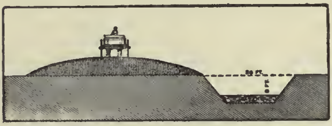


Figure 187. Cross-section of drainage canal along a roadway with earth ridge used as a roadway.

tile drain on only one side of the roadway in case of a springy hillside where the tile drain intercepts the water and prevents it flowing under the grade.

Often those in charge of roadways can enter into voluntary co-operation with farm owners to make a drainage canal which will at once drain the roadbed and adjacent fields. Thus an open, or a tile drain, through a low area, as A to B, Figure 195, will be a practical way to drain the low areas on the adjoining farms, and at the same time lower the water so that the road grade through the low area, C, E, need not be built so high to have its surface well drained. By co-operating in the expenditure, the net profit to the four farmers and to the public is greatly increased over that of building a high grade from C to E by the public and making a drain by the farmers unaided by the public fund. As was mentioned under the subject of drainage, the public, as represented by road officials, should deal liberally with owners of adjacent wet lands in co-operating and making drains needed to drain the road as well as to drain the fields, and our laws should be so constructed as to encourage the co-operation of the public and interested private parties. Thus, in Figure 195, is shown a broad marsh which needs draining. The road must either have the water level lowered by means of drainage or it must be built up rather high. If the land is peaty, a high and expensive road will be necessary, as in Figure 197, and

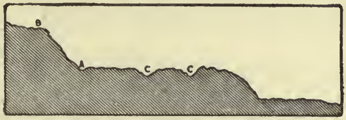


Figure 188. Uphill grade along the side of a hill. There being no ditch at A, the water from above, B, flows on the center of the road and following the wheel tracks washes gutters, C, C.

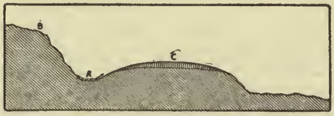


Figure 189. The same road as in Figure 188, but here a paved ditch at A collects the water and prevents its washing over the surface, C, which is thus kept dry.

the weight in the heavy grade may compress the peat, requiring an unnecessary amount of heavy earth to keep the crown of the road above standing water. If the water is lowered below the surface by means of suitable ditches, a thinner layer of clay covered with gravel will make a good roadbed. Private individuals who contemplate systems of farm drainage which might have a connection with the drainage of adjacent roadways should take into consideration the needs of the roads. Where it is practicable, they should confer with officials responsible for planning and constructing roads, that together they may devise a plan mutually useful to the landowner and the public. Here, again, we see the need of a trained official who is responsible for planning roads and to whom private individuals may go with plans for co-operative enterprises in which the public is interested.

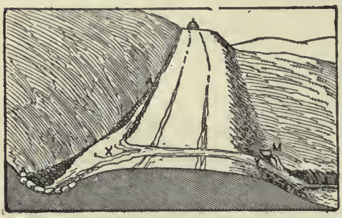


Figure 190. The water in the ditch, A, Figure 189, accumulates to a large volume on long hills and should be carried across the crown of the road, as at X, Y, and discharged on the lower side, where it can escape over the surface or be carried off in a ditch. The grade across from X to Y must be lower than the grade down the hill. A drain tile, as at M, to carry water under the crown of the road, is often much better than the "thank-you-ma'am," X, Y.

In very many cases, where the road needs an underdrain which must eventually be placed, the only practical outlet is through the tile drains in the nearly level fields adjoining. If the farmer completes his drains without considering the needs of the roadway, the tiles he uses and the grades he provides in his tile drains may not be adapted to carrying the additional water necessary to drain the roadway. It is plain that the farmer is not bound to make his drains so that the public may drain the road through them,

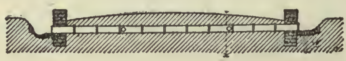


Figure 191. Culvert on hillside road with protected masonry at ends.

but the public should co-operate with him, paying such portion of the necessary expenses as is equitable and fair. Without someone to look ahead and plan the roads for permanent structures such matters do not receive attention, and no county official better earns his salary than the competent county engineer.

Grade formation.—The immense expense of making cuts and fills so as to make our public highways more nearly level, and the turnpiking of roads on nearly level lands so as to slightly elevate the crown of the road and to provide surface ditches on each side, is an enormous undertaking, because of the exceeding great length of roads. With the new impulse for more thoroughgoing road work this part of the road work of America will be carried forward with much energy, and while the plans are not always sufficiently well worked out so that the grades will not need to be remade, the work in general will move along with rapidity. Since distance is such a large element of cost in moving road material, it is often economy to purchase material from private owners near by. In other cases the requirements of the lower part of the surfacing of the roadbed may be such that it is desirable to have a layer of open, pervious material just beneath the surfacing. This is especially important where the crown of the road is but slightly elevated above the ground water, and where the mate-

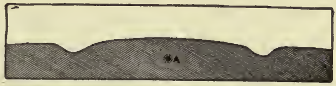


Figure 192. Drain tiles laid under the middle of the roadway.

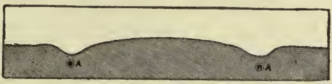


Figure 193. Line of drain tile, laid 1 to 3 feet deep, under each side of roadway.

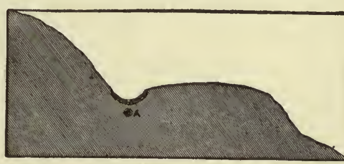


Figure 194. Drain tile used to intercept water on upper side of roadway on a springy hillside.

rial necessarily used for surfacing is such that capillary water will rise through it and keep the surfacing moist. In this case it will pay to go longer distances, or to make special effort to purchase suitable material for the upper layer of the substructure than will ordinarily be necessary.

Width of road.—Since the road laws in most states were made in pioneer times when lands were not high-priced, provision was often made for the liberal width of four rods or more for public highways. In many cases these could be cut down, and thus add to the area of the farmers' productive fields.

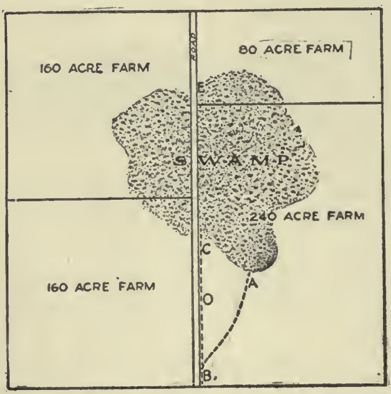


Figure 195. Both road and farms drained by a deep ditch, A, B, made by road officials and farmers co-operating, into which drains from the swamp and from the roadway lead.

The width of the surfaced grade depends upon various conditions.—In case of a much traveled road the part available for teams should be 24 feet or even wider, the ditch being outside this width. In case of cross roads 16 feet is a good average width. Farm roads entering private lands usually need to be only 8 to 12 feet wide, and simple cartways to the fields only wide enough to accommodate the ordinary wagon, 7 or 8 feet, while for bicycle paths a width of 2 to 4 feet is sufficient.

In some cases where drainage is extensively united with road making, as in very flat lands where heavy roadside ditches are needed, the crown of the road is often made 40 or more feet wide, as a matter of convenience in throwing up earth necessarily taken from the broad drains which form the roadside ditches. In other cases, as in the semi-arid regions of the central West, only a single team path or narrow roadway, rounded up with the reversible machine, making shallow side ditches, is all that is required because teams can easily turn out on either side on the solid earth.

In prominent roads, the important subject to be taken into consideration in deciding upon the width is the kind of surfacing material which will be used later on and its position on the crown of the road, whether on the center or at one side of the center. These materials are expensive and are usually laid from 9 to 16 feet wide, though wider on very prominent roads.

ECONOMIC HANDLING OF EARTH

In no part of road making has machinery been so well developed for saving labor and for making possible improved roads, as in carrying dirt from roadside ditches to the rounded roadbed in making the ordinary country dirt road. The reversible road machine is by far the most important machine in road building. The elevating grader is also a very important invention, and when large amounts of earth are to be taken from ditches on either side of the road and built up into an embankment it is very useful. While the greater adaptability of the reversible machine makes it better for lighter grading, the less cost per cubic yard of earth handled, where the grades are heavy and long, gives great im-

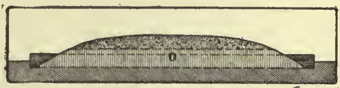


Figure 196. Cross-section of a grade across peaty land. The clay layer, O, is only a foot thick, and is covered with 8 inches of gravel. This grade is not too heavy, and has a stiff bottom zone, which will not be crushed into the peat, as in Figure 197.

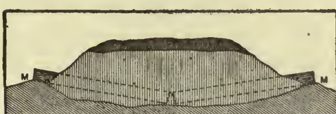


Figure 197. Heavy grade built across a marsh. The weight compresses the peat at K, and in some cases causes it to ooze out and bulge up, as at M, displacing and even breaking culverts laid to carry water from shallow ditches under the grade.

portance to the elevating grader. The slush scraper, long used for making rounded road surfaces, is now useful only where the reversible machine cannot be used, as where, owing to short length of roadway or other difficulty, the reversible machine cannot be successfully handled. The cost of moving earth from shallow ditches to the center of the road with the slush scraper is so much more than the cost of removing it with the reversible road machine that the latter is usually more practicable.

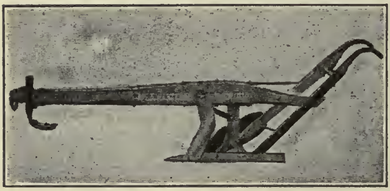


Figure 198. Railroad plow used in breaking up hard earth preparatory to handling with scraper or reversible machine.

The reversible road machine.—In Figures 198 to 201, inclusive, are shown methods of handling earth with the the reversible road machine. While no general rule can be laid down applicable to all conditions, yet the plans given in the figures mentioned will illustrate the subject so that the operator of the reversible machine will be able to figure out for each soil and roadbed a method of plowing up the earth, carrying it to the center with the blade of the reversible machine and mixing it, or laying a chosen portion on the surface, as will best economize labor and furnish the most useful roadway. In some cases the material taken from the roadside ditches is suitable for making a fairly good

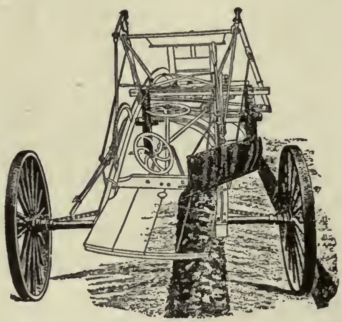


Figure 198a. Reversible machine doing its own plowing.

surface, but in the majority of instances the material thus rounded up makes a good road only when the weather is dry.

Figure 198x shows the road machine doing its own plowing in starting a ditch. Usually the better way is to first throw out a furrow-slice with a road plow, shown in Figure 198, or with a common stubble plow, then carry it over toward the center with the blade of the reversible machine. Figure 199 shows a reversible road machine shoving a furrow-slice toward the center of the turn-

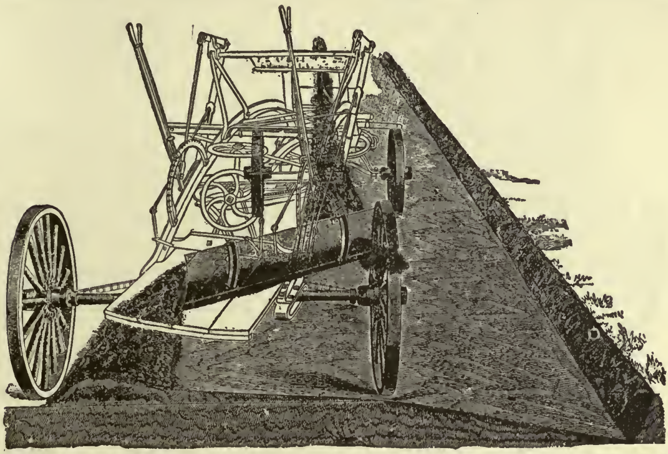


Figure 199. Reversible road machine moving a furrow-slice toward the center of the road.

pike. The blade is like an extended moldboard, which carries the earth over two or more feet each time around. These machines are called reversible, because there is a mechanism for placing the blade with the end now discharging the slice of earth in front, and the end now in front behind, thus enabling the machine to plow right-hand in one direction and, turning about, serve as a left-hand plow and throw the same furrow slice over still further. On a road with a level cross-section, where a ditch is made either side, the machine is not reversed, the teams going up one side and down the other, making the roadway into a large backfurrow. Where the roadway follows a hillside the reversible feature enables the machine to throw the dirt in the same direction one way whether drawn away from or toward the starting point.

But the immense benefit to our roads by the use of the reversible road machine, even before special surfacing is applied, is indeed very great. Mere wheel tracks cut into the surface of the native sod, and ruts and miserable mire holes in low areas are becoming things of the past, and rounded roadbeds, from which the water runs into the roadside ditches, are a very great improvement. As the desires and demands for better roads increase, and as the profits of our farms and other industries accrue so that the expense can be borne, these roadbeds will serve the most important purpose of well-formed and properly drained substructures upon which to place a surface of gravel or harder material. The reversible road machine is the forerunner of the gravel car, the stone crusher and the paving brick kiln. Even the iron rails adapted to carrying the rural electric car as well as the wheels of the produce wagon are seeking roadbeds made by the reversible road machine. Rural mail delivery, the rural industries and the social life of rural communities owe much to this simple machine.

Figure 200. Reversible road machine carrying dirt from deep roadside ditch toward the center of the road.

The elevating grader, Figures 202 to 204, inclusive, is used in a manner similar to that described for the reversible machine in grade construction. While plowing is sometimes necessary to loosen the earth that it may be easily moved by the reversible machine, the elevating grader has its own plow. Eight to sixteen horses are required to operate this powerful machine. It is managed by one man, while each driver guides four or even eight horses. It does not place the earth in position to form a well-rounded road and the reversible road machine must be used to finish the crown of the grade. In Figures 205 and 206 are shown how the earth is piled in one or two ridges according to the width between the ditches and the length of the elevating belt in use. The dotted lines in these two figures show the curved surface when the reversible road machine has been used to smooth the ridged surface left by the elevating grader.

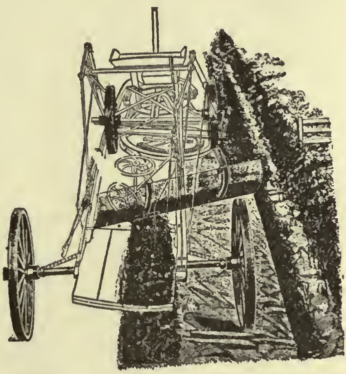


Figure 201. Reversible road machine cutting away a bank to widen an old road, showing how the blade may be set so as to reach out beyond the wheels and cut down the bank.

The drag or slush scraper (see Figure 106), in addition to being a more expensive means of carrying the earth from the ditch to the center of the road, is not so well adapted to making a good road surface as either of the machines mentioned above, though it is an indispensable implement to use in many places where it is not practicable to use the larger machines mentioned. The material thus placed in the center does not pack or wear evenly and ruts soon form in the wheel tracks. Where the reversible machine can be procured, roads which have been formed by the slush scraper can be worked over and made into much better form. In Figure 207 is shown the form of the ditch and the crown of a road originally made with the slush scraper and re-

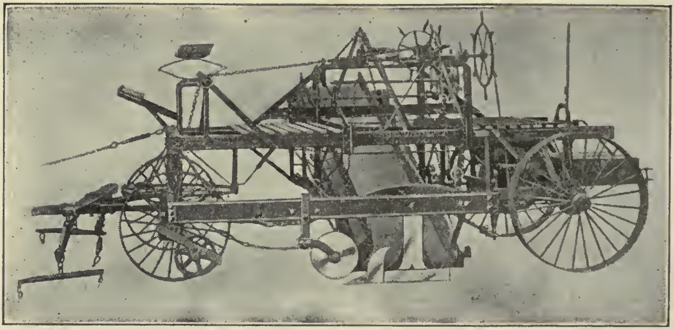


Figure 202. Elevating graders are made in different sizes. The elevators are adjustable so as to deliver the dirt near or far from the plow, or to elevate it into a dump wagon.

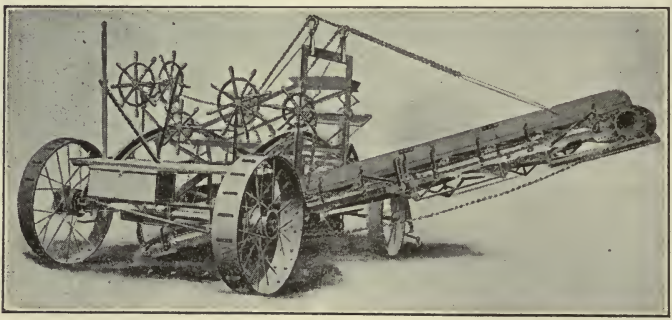


Figure 203. Elevating grader, very cheaply elevates earth out of ditches or upon long grades.

modeled with the reversible machine. The slush scraper can be advantageously used in some instances to carry the best material for the road surface to the top of the roadbed. If the best surfacing material exists in the top soil, this can be placed on the surface by carrying the subsoil forward and placing it in the bottom of the grade and carrying the surface soil backward and placing it on top of the new grade. In rare cases the difference in the quality of the material for the surface will make it economy to use the slush, wheel or Fresno scraper rather than the reversible machine, that the earth may be assorted and the best placed above, where it is

Figure 204. Elevating grader starting to plow out two roadside ditches and elevate the earth to the middle of the roadway.

utilized in making a better surface. In such cases the road can be finished by passing over several times with the reversible machine, thus shaving the grade down to a uniform line. When the road has been used for some time and the uneven packing has resulted in an uneven grade line, this can be remedied by the reversible machine. By setting the blade nearly at right angles to the line of draft, earth is carried from the high places in the road and left in the low places, thus making a smooth and uniform surface. The expert operator, with a good reversible machine, can remodel or repair the surface of very rough earth roads to a nicety. (See Slush and Fresno Scrapers, Figures 115 and 115a.

Excavating cuts and building grades.—Where the earth is to be moved not more than five rods the slush or the Fresno scraper may often be used economically. Where the material is to be moved 10 to 20 rods, the wheel scraper serves a most excellent purpose. Where material must be drawn much more than 20 rods, wagons or carts, filled by shovel or spade or with a dump upon which the earth is drawn by scrapers, are to be preferred. Where the amount of earth to be handled is large, and the distance long, dump cars on a narrow, movable iron track are more economical than wagons. Loaded cars may often be run by gravitation from the cut to the fill, a team being used to draw the emptied train back to the pit. By means of side switches or double tracks two or more trains can be operated at once. In some cases the wire cable may serve as a track for carrying iron hanging barrows full of earth across places where it is not practicable to use wagons nor to build a track for dump cars.

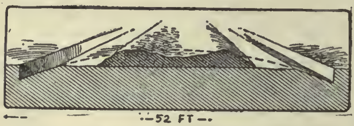


Figure 205. Earth as left by the elevating grader in two ridges on a wide road where the belt is not long enough to carry it to the center. By means of the reversible machine these ridges are easily distributed along the sides and in the center, making a rounded crown as shown by the curved line.

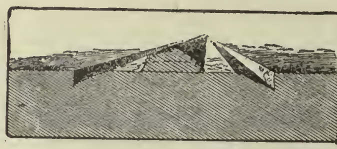


Figure 206. Earth as left by the elevating grader in one ridge on a narrow road. The dotted line shows the curve over the crown after the reversible machine has been used to finish the surface.

Placing the materials of the grade.—For the bulk of a heavy grade any solid earthy material will serve the purpose, unless it be quicksand, which will not stand up. In some instances earth which will not be washed out by rain and is adapted to supporting grass with a strong sod, should be placed on the outer slanting edge of the grade. But there is much room for choice in selecting the material for the upper layer of the subsurface and for the material of the surface of the roadbed. Materials from the cut should be so chosen for the upper part of the substructure that the gravel or other surfacing material may have a dry, firm bed to lie on. By this means, the amount of surfacing materials needed will often be reduced and the expense of a good road be made less. Placing the materials systematically, and carefully tramping each load, is necessary in some cases, but where the grade may be given a year in which to settle before placing a permanent surface, it may easily be leveled down with a reversible road machine before the final surfacing is laid.

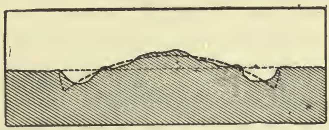


Figure 207. The solid line shows the rough roadbed as left by the slush, Fresno or wheel scraper. The dotted line shows the graded and rounded surface after it is dressed up with the reversible road machine.

The crowns and side ditches.—The form of the cross-section differs with the surfacing materials used and with some other conditions. In case of loose gravel and of clay the steepness of the crown should vary from ¾ inch to 1½ inches to the foot.

Where the center of the road is made up of materials which will be compacted or rapidly worn by travel, the slope from center to side is made considerable. Where the surface is hard and durable, thus forming a perfect watershed, the road may be more nearly level because it is better to travel over in this condition. In some earth roads which are built very broad, because of the large amount of earth from large drainage ditches at either side used in draining nearly level lands, it is necessary to use special means of draining the center of the roadway. In Figure 208 is shown how "top

Figure 208. Heavy side ditches with outer banks 54 feet apart, with 20-foot roadway and small side ditches, A and B, at top of high grade, with grass seeded on sides of grades A, C and B, D. Often in very heavy clay roads these grassed sides can be used when the roadway, A, B, is wet and soft.

ditches" may be used to allow a sharper crown to be made in a narrow roadway in the center of the wide grade. Small spade ditches from these top ditches will carry the water to the drainage ditch below and, by proper management, the area between the top ditch and the main ditch can often be used for travel. In level countries made up of fine clay which is likely to drift before the wind and leave a deposit in the large ditch along the sides of the road, these top ditches sometimes serve as a temporary expedient in repairing the road until such time as the main drainage ditches can be cleaned out and the grade dressed up anew. Top ditches may sometimes be advantageously used between the main roadway and the bicycle path to prevent teams being driven on the grassy or improved bicycle path on the slope.

CONSTRUCTING THE ROAD SURFACE

A complete catalogue of the materials used for surfacing roads would be extensive. The attempt here will be to discuss only the several groups of these materials.

Common earth and sand are, of necessity, as yet, more used for roadways than are all other classes of materials, since the soil or subsoil thrown up beside the road is easiest utilized for the roadbed. Soils composed largely of clay, when wet, are so soft, so easily cut into deep ruts, and cling so tenaciously to the wheels of vehicles and to the feet of animals, that they are the most unsatisfactory of all raw materials; yet when dry and hard they make most excellent roads. Fine sand, on the other hand, is nearly as objectionable as soft clay. The sand becomes pulverized when dry, allowing the wheels of vehicles to sink so deep that they are dragged forward with great labor by draft animals which have a poor footing; bicycles and motor vehicles traverse such roads with great difficulty. When clay and sand are found mixed in the proportion of about one part of clay to three parts of sand, or when this mixture is artificially made, the road is very much improved. (See note on cost of sand-clay roads, page 295.)

Gravel as surfacing material.—While gravel does not make as durable roads as crushed stone, it is prepared much cheaper, is very widely distributed, and can be so cheaply procured, in many cases, that it is our most widely useful road-surfacing material.

Very many grades or forms of gravel are to be found; some coarse, others fine; some round, others subangular; some soft, as limestone pebbles; others hard, as pebbles of granite or trap rock. The sharper and harder the gravel the better, as a rule. The size which is most desirable differs somewhat with the hardness, form and other characters of the gravel. Some gravels have clay and other binding materials mixed in with them. In some cases gravel has been found containing sufficient iron so that the roadbed composed of it became cemented and hardened into a stonelike crust.

Stones which are valuable for roads.—The trap rock of the palisades near New York City, owing to its hardness and wearing ability, is freighted hundreds of miles by canal and by rail to be used on road surfaces. The immense deposits of trap rock at Duluth and at other points in Minnesota will likewise be of great value in making roads in the west. The rock at Duluth might be transported by rail; and by boat it could be cheaply freighted to Milwaukee, Chicago, Detroit, Buffalo and other cities on the great lakes. From Taylors Falls, in addition to the railways, the St. Croix and Mississippi rivers furnish a cheap waterway for floating trap rock to the cities along the banks of the Mississippi river.

The difficulty in making macadam and telford roads is the immense cost of quarrying, crushing and transporting the heavy rock. While there are many streets and roads leading to the country from large towns, and prominent roads between towns, on which the travel is sufficient to warrant the county and city, aided by the state, to make stone roads, still, owing to the cost, this form of structure can be used on but a small proportion of our roadways. We must be content to use gravel on many of our improved roads, only slowly changing the most important roads to macadam.

Wood and metal are used to a small extent in making

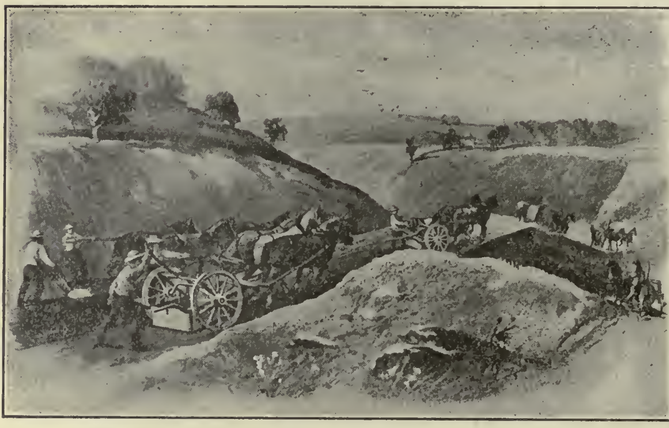


Figure 209. Wheelers, and plow, carrying earth from cut to grade.

roadways. Wood lacks the quality of endurance, and is becoming more expensive. Iron is very desirable, but its great cost precludes its use except in very limited quantities in special cases. Artificial stone, such as is used in city streets and walks, has not been found practical for country roads. Paving brick, however, is coming into use in some important roadways, and is, no doubt, destined to be of great use in road making. This material, laid in strips 8 or 10 feet wide in the center, or at one side of the center, of the road, makes a very satisfactory driveway. Where ashes can be procured, they make a most useful substance for hardening the surface of the road and to use as the lower portion of the surface in bicycle paths.

Mixing surface materials.—The mixing of materials in making up the surface of the roadway until recently has been but little studied from a scientific standpoint. As a general proposition, however, under the ordinary climatic conditions of the United States, it may be said that a mixture of about equal parts of gravel, sand and

Figure 210. Dump wagon, with lever and chain gear to open and close drop bottom.

clay forms a good compact road surface, when the subsoil is not miry. The road builder must constantly use his judgment in mixing the best materials secured from cuts, from the roadside or from adjacent fields in making up the dirt, gravel or sand-clay surface of the roadbed of the common road. Where the top of the substructure is made up of mixed sand and clay, and possibly some gravel, the problem is how to add gravel or other coarse material which will make the road carry a heavier load without cutting, will be smooth and hard on the surface, and will endure the constant wear of travel. If the mixed soil contains considerable clay, coarse gravel mixed in it will improve the body of the crust of the roadbed, and if on top of this is placed some fine hard gravel, a fairly good road will result. If the surface is composed largely of fine clay with very little sand or gravel entering into its composition, a still larger

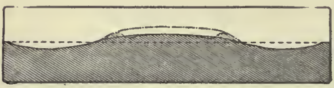


Figure 211. Grading substructure for a macadam surface, with shoulders against which the rock rests.

Figure 212. First course of stone on a macadam road as it appears when spread ready for rolling.

amount of gravel will be necessary to give the solidity or carrying strength required by the road surface.

If, on the other hand, the surface of the grade is composed of sand, it will often be best to use gravel, or gravel into which a small amount of clay is mixed, or clay alone may be mixed with the sand. Sand really

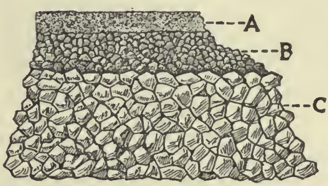


Figure 213. Three courses of a macadam surface, 8 to 12 inches deep.

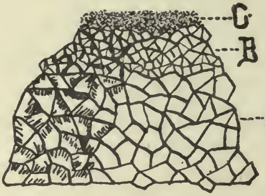


Figure 214. Section of macadam surface. A, 2 to 3-inch rock; B, 1 to 2-inch sizes; C, fine rock and dust.

makes a better substructure than clay, because any water that penetrates the surface can easily percolate downward, leaving the roadway dry.

Where gravel, sand, clay, ashes, shells or other similar materials are hauled from a distance, much expense can often be saved by using only that amount which, when mixed with the earth already on the road, will make a good surface, instead of building up the entire road crust out of the material hauled.

Quantities of gravel for roads of different widths and depths

From the New Jersey Road Report is quoted the following table which gives the number of cubic yards of gravel required in the construction of one mile of gravel road of widths varying from 6 feet to 20 feet and depths from 6 to 11 inches. These quantities should be multiplied by 1 1-2 to give the number of cubic yards of loose gravel required to make the depths given below of compact gravel.

Number of ft. in width, road 1 mile long	Number of cu. yds. in road 6 in. deep	Number of cu. yds. in road 7 in. deep	Number of cu. yds. in road 8 in. deep
6	586 2-3	684 4-9	782 2-9
7	684 4-9	798 14-27	912 16-27
8	782 2-9	912 16-27	1,042 26-27
9	880	1,026 2-3	1,173 1-3
10	977 7-9	1,140 20-27	1,303 19-27
11	1,075 5-9	1,254 22-27	1,434 2-27
12	1,173 1-3	1,368 8-9	1,564 4-9
13	1,271 1-9	1,482 26-27	1,694 22-27
14	1,368 8-9	1,597 1-27	1,825 5-27
15	1,466 2-3	1,711 1-9	1,955 5-9
16	1,564 4-9	1,825 5-27	2,085 25-27
17	1,662 2-9	1,919 7-27	2,216 8-27
18	1,760	2,053 1-3	2,346 2-3
19	1,857 7-9	2,167 11-27	2,477 1-27
20	1,955 5-9	2,281 13-27	2,607 17-27
	9 in. deep	10 in. deep	11 in. deep
6	880	977 7-9	1,075 5-9
7	1,026 2-3	1,140 20-27	1,254 22-27
8	1,173 1-3	1,303 19-27	1,434 2-27
9	1,320	1,466 2-3	1,613 1-3
10	1,466 2-3	1,629 17-27	1,792 16-27
11	1,613 1-3	1,792 16-27	1,971 23-27
12	1,760	1,955 5-9	2,151 1-9
13	1,906 2-3	2,118 14-27	2,330 10-27
14	2,053 1-3	2,281 13-27	2,509 17-27
15	2,200	2,444 4-9	2,688 8-9
16	2,346 2-3	2,607 11-27	2,868 4-27
17	2,493 1-3	2,770 10-27	3,047 11-27
18	2,640	2,933 1-3	3,226 2-3
19	2,786 2-3	3,096 8-27	3,405 25-27
20	2,933 1-3	3,259 7-27	3,585 5-27

Spreading and compacting earth and gravel surfaces.— One very important consideration in constructing the wearing surface of a road is evenness. The materials should be so mixed that the wheel tracks will wear evenly. To accomplish this result requires that a uniform mixture be made and that it be spread evenly and thoroughly compacted. Thus, in making a mixture of coarse gravel, sand and clay, which should be 6 to 12 inches deep according to the quality of the substructure and to the requirements of travel, the different materials can be put on in layers. The first layer can be put on the substructure which has been carefully smoothed with the road machine; after having been dumped from the wagon or scrapers, this layer may be smoothed off and made uniform in thickness by the blade of the road machine. Another layer may then be placed in a similar manner, and finally the third layer. The plow or disk harrow may now be used to thoroughly mix together all of the layers.

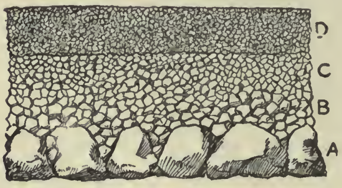


Figure 215. Heavy telford road surface. A, large rock; B, 2 to 3-inch rock; C, 1 to 2-inch sizes; D, fine rock and dust.

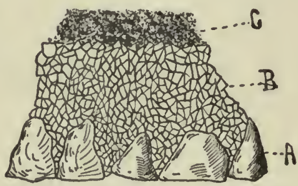


Figure 216. Section of telford road surface. A, large stones laid by hand at bottom of road; B, 2 to 3-inch rock laid over the large stones; C, 1 to 2-inch stone; surfacing of small particles of rock.

After each plowing or disking, the common field harrow should be used to level down the surface. By repeating the plowing or disking several times, an even mixture may be produced. If desired, a thin layer of gravel may then be placed on the surface. Only very general directions can be given, since different materials must be mixed in different proportions and each mixture may require special treatment. In many cases it will


Figure 217. Transverse section of telford road with macadam surface.

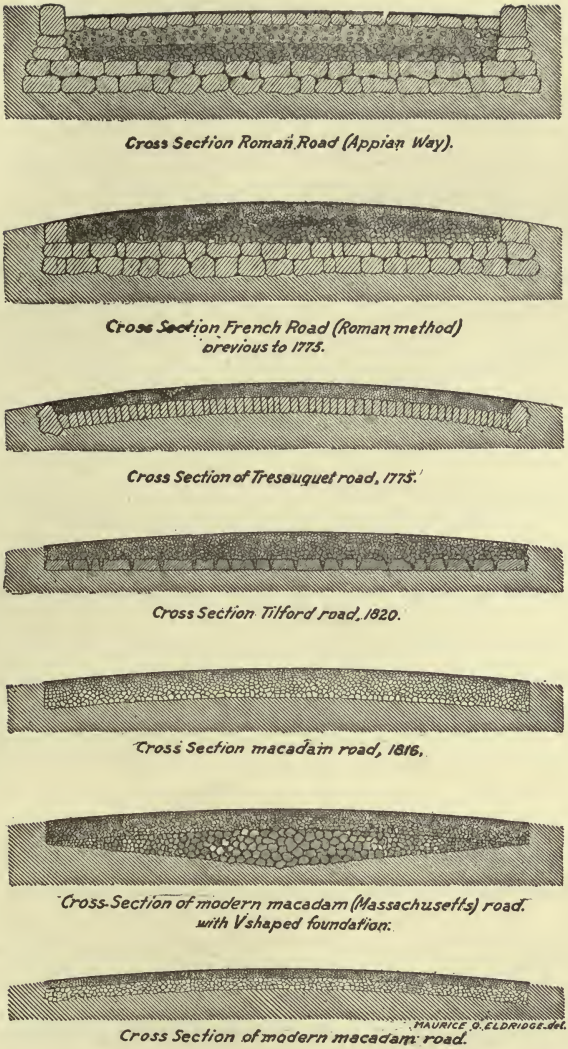


Figure 218. Several forms of stone roads, showing historical types. Prepared by Maurice O. Eldridge.

be wise to put the surfacing material on in two or three general layers, thoroughly mixing and smoothing the first before adding the next.

The roller is a very important machine for compacting the roadway and its use can hardly be overestimated in road construction. It should be used after the mixing and smoothing is completed, both on the upper layer and on the layers beneath. During the progress of the work, any large stones which happen to be in the gravel or clay should be carefully removed or broken up.

Figure 219. Macadam road on one side of the center of the grade and an earth track on the other side.

MACADAM STONE ROADS

In preparing the bed for a macadam road, a strip, 10 feet or more in width, at the center or at the side of the center of the crown should first be prepared. This can be done in soils free from stone by using the reversible road machine, drawing some earth out of the proposed roadway and leaving a slight embankment against which to place the stone at either side, as shown in Figure 211.

Crushed rock for macadam roads.—The granite, trap rock, limestone, sandstone or other hard stone used for the lower portion of the macadam roadway should be in pieces from 2 to 3 inches in diameter. Where softer rock, as limestone, can be more cheaply secured it may be used for the lower courses, using trap rock or other better-wearing rock for the surface. In some cases harder and softer rocks may be mixed, though this must be done with the greatest care, to prevent uneven wearing. If the stone is to be laid 12 inches deep, crushed stone of this size can be used for the lower 8 or 9 inches. The next layer of 2 to 3 inches should be of stone about half the diameter mentioned. On top of this should be laid broken stone not more than 1 inch in diameter, and into it should be worked the fine particles and dust from the crusher. Sand or broken limestone may also serve as binding materials and be worked into the surface.

After placing the first layer of coarse rock it should be thoroughly rolled with a heavy roller. A steam roller is preferred. Rather than roll the road with too heavy a roller, it should be gone over many times with a

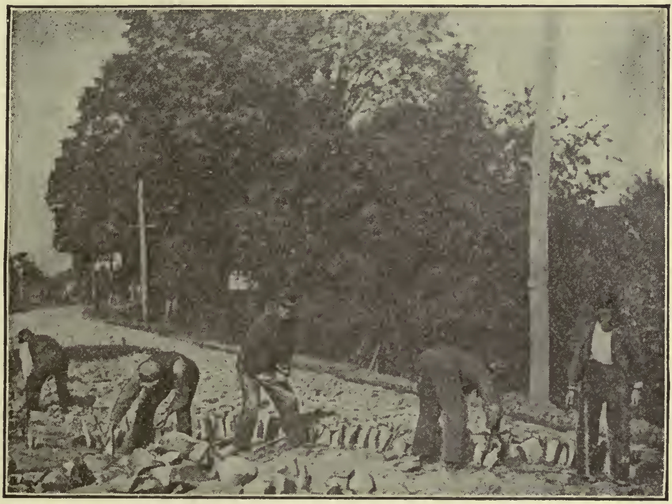


Figure 220. Laying lower course of a telford road.

machine of medium weight. The object is not so much to embed the stones into the underlying clay, as to work them about so that each stone finds the smallest place into which it will fit. Rock which, when crushed between the jaws of a rock crusher, breaks into angular forms, nearly cubical, may thus be kneaded together into a harder crust than rocks which crumble up or do not have sharp, hard edges, and rough surfaces.

The selection of materials for macadam roads.*—No one rock can be said to be a universally excellent road material. The climatic conditions vary so much in different localities, and the volume and character of traffic vary so much on different roads, that the properties necessary to meet all the requirements can be found in no one rock. If the best macadam road be desired, that material should be selected which best meets the conditions of the particular road for which it is intended.

In most cases the selection of a material for road making is determined more by its cheapness and convenience of location than by any physical properties it may possess. But when we consider the number of roads all over our country which are bad from neglect and from obsolete methods of maintenance that would be much improved by the use of any rock, this regard for economy is not to be entirely deprecated. At the same time, as a careless selection leads to costly and inferior results, too much care cannot be used in selecting the proper material when good roads are desired at the lowest cost.

In selecting a road material it is well to consider the agencies of destruction to roads that have to be met. Among the most important are the wearing action of wheels and horses' feet, frost, rain, and wind. To find materials which can best withstand these agencies under given conditions is the great problem that confronts the road builder.

Before going further, it will be well to consider some of the physical properties of rock which are important in road building, for the value of a road material is dependent in a large measure on the degree to which it possesses these properties. There are many such properties that affect road building, but only three need be mentioned here. They are hardness, toughness, and cementing or binding power.

By hardness is meant the power possessed by a rock to resist the wearing action caused by the abrasion of wheels and horses' feet. Toughness, as understood by road builders, is the adhesion between the crystal and fine particles of a rock, which gives it power to resist fracture when subjected to the blows of traffic. This important property, while distinct from hardness, is yet intimately associated with it, and can in a measure make up for a deficiency in hardness. Hardness, for instance, would be the resistance offered by a rock to the grinding of an emery wheel; toughness, the resistance to fracture when struck with a hammer. Cementing or binding power, is the property possessed by the dust of a rock to act after wetting as a cement to the coarser fragments composing the road, binding them together and forming a smooth, impervious shell over the surface. Such a shell, formed by a rock of high cementing value, protects the underlying material from wear and acts as a cushion to the blows from horses' feet, and at the same time resists the waste of material caused by wind and rain, and preserves the foundation by shedding the surface water.

*Extracts from a paper on this subject, from the Yearbook, Department of Agriculture, for 1900, by Logan Waller Page.

Binding power is thus, probably, the most important property to be sought for in a road-building rock, as its presence is always necessary for the best results. The hardness and toughness of the binder surface more than of the rock itself represents the hardness and toughness of the road, for if the weight of traffic is sufficient to destroy the bond of cementation of the surface, the stones below are soon loosened and forced out of place. When there is an absence of binding material, which often occurs when the rock is too hard for the traffic to which it is subjected, the road soon loosens or ravels.

Experience shows that a rock possessing all three of the properties mentioned in a high degree does not under all conditions make a good road material; on the contrary, under certain conditions it may be altogether unsuitable. As an illustration of this, if a country road or city parkway, where only a light traffic prevails, were built of a very hard and tough rock with a high cementing value, the cheapest results would not be obtained. Such a rock would so effectively resist the wear of a light traffic that the amount of fine dust worn off would be carried away by wind and rain faster than it would be supplied by wear. Consequently, the binder supplied by wear would be insufficient, and if not supplied from some other source the road would soon go to pieces. The first cost of such a rock would in most instances be greater than that of a softer one, and the necessary repairs resulting from its use would also be very expensive.

There are some rocks, such as limestones, that are hygroscopic, or possess the power of absorbing moisture from the air, and in dry climates such rocks are distinctly valuable, as the cementation of rock dust is in a large measure dependent for its full development on the presence of water. The degree to which a rock absorbs water may also be important, for in cold climates this to some extent determines the liability of a rock to fracture by freezing. It is not so important, however, as the absorptive power of the road itself, for if a road holds much water the destruction wrought by frost is very great. This trouble is generally due to faulty construction rather than to the material. The density or weight of a rock is also considered of importance, as the heavier the rock the better it stays in place and the better it resists the action of wind and rain.

Rocks belonging to the same species and having the same name, such as traps, granites, quartzites, etc., vary almost as much in different localities in their physical road-building properties as they do from rocks of distinct species. This variation is also true of the mineral composition of rocks of the same species, as well as in the size and arrangement of their crystals. It is impossible, therefore, to classify rocks for road building by simply giving their specific names. It can be said, however, that certain species of rock possess in common some road-building properties. For instance, the trap rocks as a class are hard and tough and usually have binding power, and consequently stand heavy traffic well; and for this reason they are frequently spoken of as the best rocks for road building. This, however, is not always true, for numerous examples can be shown where trap rock having the above properties in the highest degree has failed to give good results on light traffic roads. The reason trap rock has gained so much favor with road builders is because a large majority of macadam roads in our country are built to stand an urban traffic, and the traps stand such a traffic better than any other single class of rocks. There are, however, other rocks that will stand an urban traffic perfectly well, and there are traps that are not sufficiently hard and tough for a suburban or highway traffic. The granites are generally brittle, and many of them do not bind well, but there are a great many which when used under proper conditions make excellent roads. The felsites are usually very hard and brittle, and many have excellent binding power, some varieties being suitable for the heaviest macadam traffic. Limestones generally bind well, are soft, and frequently hygroscopic. Quartzites are almost always very hard, brittle, and have very low binding power. The slates are usually soft, brittle and lack binding power.

There are but two ways in which the value of a rock as a road material can be accurately determined. One way, and beyond all doubt the surest, is to build sample roads of all the rocks available in a locality, to measure the traffic and wear to which they are subjected, and keep an accurate account of the cost both of construction and annual repairs for each. By this method actual results are obtained, but it has grave and obvious disadvantages. It is very costly, especially so when the results are negative, and it requires so great a lapse of time before results are obtained that it cannot be considered a practical method when macadam roads are first being built in a locality. Further than this, results thus obtained are not applicable to other roads and materials. Such a method, while excellent in its results, can only be adopted by communities which can afford the necessary time and money, and is entirely inadequate for general use.

The other method is to make laboratory tests of the physical properties of available rocks in a locality, study the conditions obtaining on the particular road that is to be built and then select the material that best suits the conditions. This method has the advantages of giving speedy results and of being inexpensive, and as far as the results of laboratory tests have been compared with the results of actual practice they have been found in the majority of cases to agree.

These tests can be made without expense to local authorities, as the Office of Public Roads in the Department of Agriculture maintains at Washington a complete laboratory in which is tested, free of charge, all samples of road materials submitted by any officer in charge of public road construction in the United States.

Placing the layers of macadam roadway.—The second layer of macadam is placed on the well-rolled first layer, and it in turn is thoroughly rolled. When sprinkled on the rock during the rolling process helps to slide the surfaces into firm, locked positions. When this second layer has been rolled many times, the third layer is applied and the fine binding material is gradually added as the roller, by repeated application to the particles of stone, crushes and works them into position. After adding the fine binding materials, the application of water to assist the roller in hardening the surface is of special importance. The choice of rock for the surface stone is very important. It should be both hard and capable of cementing. In some cases, some tougher granitic and trap rocks can be mixed with limestone, so that the latter may help cement the tougher stones which better endure the wear of travel.

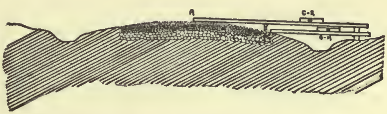


Figure 221. A, crown of macadam road; B, outer edge of stone surface; C-K, level on straight edge in position to compare A with level on guide stake; O-M, straight edge in position to test level at outer edge of stone surface.

To secure the proper depth of each of the three layers, stakes are placed at either side of the line of the road, on which are marked the height of the crown and also the height of each of the layers. By occasionally measuring across from these heights, the desired height can be secured at all points. Figure 221 shows how these measures may be taken by means of a straight edge and mason's level. The telescope leveling instrument with measuring rod may also be used where great accuracy is desired.

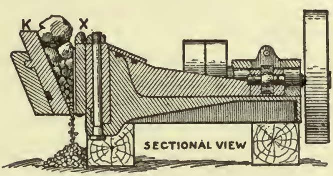


Figure 222. Cross-section of a rock crusher showing the stationary jaw, X, and the oscillating jaw, K, with rock between.

Macadam roadways must be built sufficiently thick so that the wheels will not break down the stone or punch them into the soil beneath. Seven to 9 inches is as thin as it is usually practicable to make these roads, and for much heavy travel 12 or more inches is necessary.

Telford roads.—Where stone roads are placed on spongy ground, they are sometimes broken by being crushed down into the soft earth beneath. The telford road was designed to better suit this condition. As shown in Figures 215, 216 and 217, the first layer is made up of stones 6 to 12 inches thick, laid with their broad

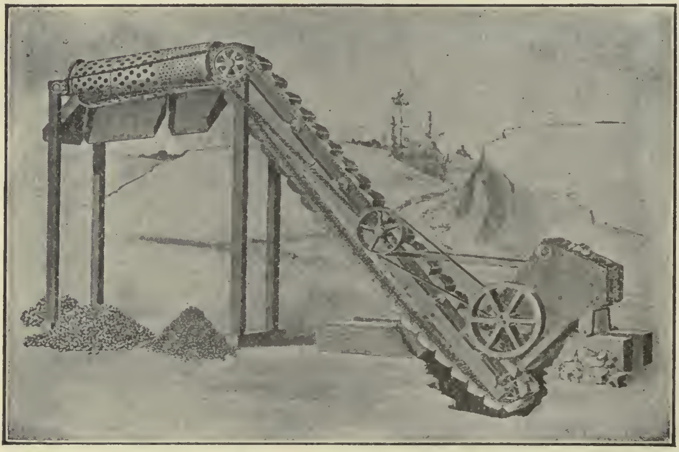


Figure 223. Rock crusher with elevator and screen. The man-size rocks are placed in the hopper, and as they are broken the crushed rocks fall into the cups and are carried up to the cylindrical revolving screen. The finer particles fall through the smaller holes, the medium sized crushed stones fall through the larger holes and the larger stones run out at the end of the cylinder.

surfaces on the bottom and their narrow edges toward the top. These stones must be placed by hand. Between these stones is placed crushed rock, similar to that comprising the lower layer in macadam roads, in sufficient quantity to make a covering several inches thick. The next layer and the top layer of fine materials are placed in the same manner as in macadam roads. For a given amount of material used, there is little advantage in this method. In no case should the upper surface of the larger rocks be near the surface. They should be covered with several inches of finely crushed stone. Particles of stone lying on top of a hard rock and struck with the tire of a wagon are subjected to a sudden blow, as the hammer strikes a walnut laid on an anvil. For this reason rock at this point may become crushed and result in forming a rut.

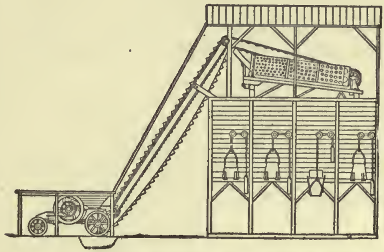


Figure 224. Cross sectional view of a semi-stationary rock-crushing plant. Wagons are driven under the four compartments, and the crushed stone runs into the wagon box.

Rock crushers.—In Figures 222 to 225, inclusive, are shown rock crushers. Where the rock is to be used in large quantities, a crushing plant should be so devised and developed that comparatively little manual work is necessary. The rock can be loosened from the ledge by means of the drill and blast and sometimes further broken by hand, and then placed in wheelbarrows run on cables, or on dump cars, and thus carried to the crusher by power machinery. Some hand work is necessary to feed the crusher. The crusher, propelled by a powerful engine, breaks the stone between hard steel plates. The broken particles of stone fall into an elevator and are carried to a revolving screen. The finest

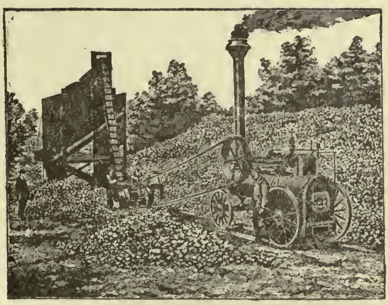


Figure 225. Stone-crushing plant in operation.

particles fall out through small holes near the end of the revolving screen next to the crusher, and the medium-sized particles fall from a screen with larger holes, while the largest particles (to be used in the bottom of the macadam road) pass the largest openings, and run out from the lower end of the screen. These are called "tailings." Tailings are frequently run through the crusher again. The bin under each portion of the screen catches the material as assorted in the three sizes. From the bins the large, the medium-sized and the finely crushed rock are taken by team, preferably in specially constructed distributing carts, and put upon the road, or if the road is at some distance from the crusher, they are transported in flat cars or in boats to the vicinity of the road. It is here placed in carts or wagons and carted to the roadway and laid as above described.

Revolving screen and dust jacket.—For small, portable plants ordinarily used in country road work, a revolving cylindrical screen is used. It is about 8 to 10 feet long and 24 to 30 inches in diameter, and is usually divided into three sections of equal length. When the harder and tougher rocks are to be crushed, the first section is punched with holes about ¾ of an inch in diameter, the second about 1¾ inches in diameter, while the third section is punched with holes about 2¾ inches in diameter. Where limestone and softer varieties of rock are used, the screen is punched with holes about as follows: First section, 1 inch in diameter; second section, 2 inches, and third section, 3 inches. The latter screen separates the rocks into sizes about as follows: ¾ inch down to dust, from the first section; ¾ to 1½ inches from the second section; and 1½ to 2½ inches from the third section. For traps and other harder and tougher rocks, the screen, being provided with the smaller holes indicated above, separates the rocks into sizes about as follows: ½ inch down to dust from the first section; ½ to 1¼ inches from the second section; and 1½ to 2½ inches from the third section. The softer rocks are crushed and separated into the larger sizes for the reason that they will wear better not being so easily broken or crushed by the traffic. The harder and tougher rocks have to be crushed smaller, otherwise they will not bind or form a solid, compact mass. In the higher classes of macadam work, a dust jacket is made so as to cover about three-fourths of the area of the first section of the screen. The purpose of the dust jacket is to separate the stone dust from the screenings in order that it may be placed last on the top course so as to be used as a binder for the screenings. If the dust is not separated from the screenings most of it will sift to the bottom of the first course as soon as the screenings are spread, and its value as a binding material will be partially lost.

Cost of crushed rock.—In large quantities trap rock could be placed on cars or boats at such shipping points as Taylors Falls or Duluth, Minn., at a very low price per cubic yard, as could also granite at St. Cloud, Minn. Large contracts have been filled at the Palisades, New York, at a very low price per ton. Trap rock can be carried by boat from Duluth to Chicago or Buffalo, sometimes as ballast, at a small price per ton. For each mile of macadam road, 12 feet wide and 10 inches deep, about 2,000 cubic yards of rock are needed. If the lower 7 inches are of limestone and the upper 3 inches of trap rock, 1,400 cubic yards of limestone and 600 cubic yards of trap rock are required. At common prices for freight these amounts make the use of stone roads impossible except in occasional much-used roads where the people have the means for the large expenditure required.

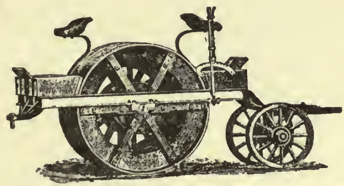


Figure 226. Reversible road rollers to be drawn by horses, built to weigh 2 to 6 tons.

Quantities of crushed rock required for different widths and depths.—The following table, which is quoted from the Report of the State Commissioner of Public Roads of New Jersey, approximates the number of tons of rolled stone required to construct a mile of road of the various widths and depths. The New Jersey Commissioner says in explanation of the table:

"The basis is 3,000 tons of loose stone or 3,500 tons of compressed stone for a road one mile long, 16 feet wide and 8 inches deep. A road 8 inches deep, when finished, will have required at least 10 inches of stone. It should be placed in two layers of 5 inches each, and each layer rolled down to 4 inches. Then the application of the ¾ inch and screenings will bring the road to the prescribed depth; for other thicknesses the stone should be placed in proportion to the intended finished depths."

Quantities of crushed rocks for different widths and depths of roads

Width in feet	Depth in inches		Tons of stone per mile
8	4	will require	875
8	6	"	1,312
8	8	"	1,750
8	10	"	2,187
8	12	"	2,625
9	4	"	984
9	6	"	1,476
9	8	"	1,968
9	10	"	2,460
9	12	"	2,953
10	4	"	1,093
10	6	"	1,640
10	8	"	2,187
10	10	"	2,734
10	12	"	3,281
11	4	"	1,203
11	6	"	1,804
11	8	"	2,406
11	10	"	3,007
11	12	"	3,609
12	4	"	1,312
12	6	"	1,968
12	8	"	2,625
12	10	"	3,281
12	12	"	3,937
13	4	"	1,421
13	6	"	2,132
13	8	"	2,843
13	10	"	3,554
13	12	"	4,265
14	4	"	1,531
14	6	"	2,296
14	8	"	3,062
14	10	"	3,828
14	12	"	4,593
15	4	"	1,640
15	6	"	2,460
15	8	"	3,281
15	10	"	4,101
15	12	"	4,921
16	4	"	1,750
16	6	"	2,625
16	8	"	3,500
16	10	"	4,375
16	12	"	5,250

Quantities of crushed rocks for different widths and depths of roads—Continued

Width in feet	Depth in inches		Tons of stone per mile
17	4	will require	1,859
17	6	"	2,789
17	8	"	3,718
17	10	"	4,648
17	12	"	5,578
18	4	"	1,968
18	6	"	2,953
18	8	"	3,937
18	10	"	4,921
18	12	"	5,906
19	4	"	2,078
19	6	"	3,117
19	8	"	4,156
19	10	"	5,195
19	12	"	6,234
20	4	"	2,187
20	6	"	3,281
20	8	"	4,375
20	10	"	5,468
20	12	"	6,562

Under some conditions hard roads can best be made of paving bricks, granite blocks, cement blocks, flat rocks, or cobblestones, and under other conditions even iron wagon tracks may be used.

The discovery of immense quantities of easily mined iron, the improvements in iron smelting and in the manufacture of steel plates, together with the cheapened transportation, have brought iron rails almost within the possibility of large use in road making. It is not likely, however, that they will come into prominent use for roadways, except possibly across much-traveled bridges, where they will receive and endure the wear which would cause boards or asphalt to be so rapidly worn out as to be more expensive than the steel tracks. One thing in favor of steel tracks on roads very much traveled is the saving on draft on teams; there being very little friction, the force required to draw the load is very light.

The following table, according to Prof. King, shows the amount of power in pounds required to draw a load on an ordinary farm wagon, on a level road made of each of the following materials other than iron:

On cubical block pavement, 28 to 44 lbs. per ton.
On macadam road, 55 to 67 lbs. per ton.
On gravel road, 75 to 140 lbs. per ton.
On plank road, 25 to 44 lbs. per ton.
On common dirt road, 75 to 224 lbs. per ton.

REPAIR AND MAINTENANCE OF ROADS

Repairing common roads.—Much is gained in the building of roads if the surface is made uniform through

Figure 227. Steam road roller.

long sections, that the same method of repairing may be followed throughout. While the most important work in road repairing is to attend to the little things, as breaks in the surface, yet there is a time when the entire surface must be systematically worked over with machinery, or the entire surface be reconstructed of new materials. The most extensive repair work is that which is needed to keep earth and gravel roads smooth, compacted and round, so that the water will run off into the side ditches and the surface be kept hard. Much of this work can be done by the reversible machine, in some cases followed by the road roller.

By going over the dirt or gravel road two or more times annually an experienced man can keep the center of the roadway free from ruts and so rounded as to be

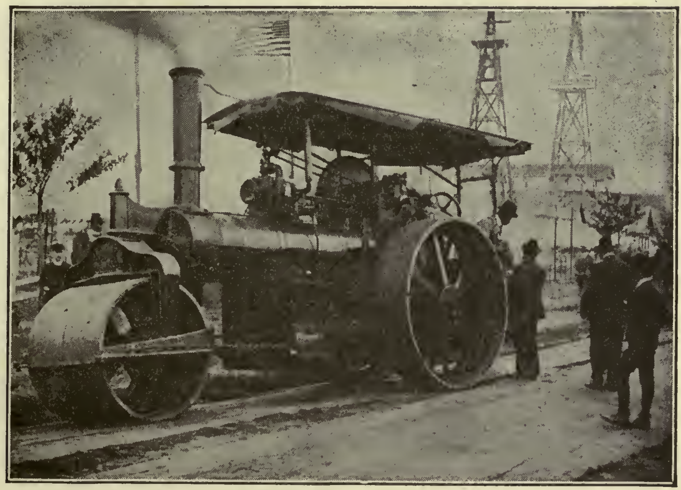


Figure 228. Steam road roller.

dry and smooth except in times of excessive rainfall. There is no portion of our road work more neglected than that of repairing. By looking after the roads when they are drying out just after the spring rains, the surface can be formed up so as to last during the drier part of the summer. In the drier portions of the west, smoothing up in the early part of the summer season will often be sufficient for the entire year, while in sections of greater rainfall, together with more travel, the road machine should dress the roadway up two or three times annually, unless, with the king road machine, this is done after each rain, making the use of the reversible machine unnecessary.

The split-log drag.—Next in importance to the reversible road machine, and possibly, in the aggregate, more important, is the drag made of the two parts of a split log. Like a spade, it is a very simple implement. Figures 234 and 235 show how it is constructed. A log 10 or 12 inches in diameter and 7 to 9 feet long is split and fastened together as shown. The team is hitched to the chain one side the center and the drag is drawn at an angle. The driver stands on the machine, and by driving up one side and down the other, he shoves the dirt toward the center, if that is needed; he scrapes down high points and fills up ruts, and both smooths and compacts the surface. The work is begun early in the spring and is done when the clods of the dirt are hardening after rains, when travel has made the surface rough, and at such times as teams can best be spared for this work. The road will thus be kept relatively smooth throughout the year, and will become better compacted from year to year. This device will serve on many gravel roads quite as well as on earth roads. This repair work should be done at public expense. Each section of road can be arranged for under a contract with a farmer. The road officer can call the contractors out by telephone or postcard, thus making repairs when most profitable.

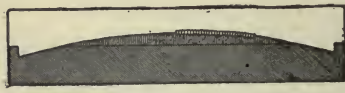


Figure 229. Road with track 9 feet wide one side of the center laid with brick. Below the brick there must be a layer of gravel or other solid material several inches deep, as when wet bricks are crushed into a clay bed by the wheels of heavy vehicles.

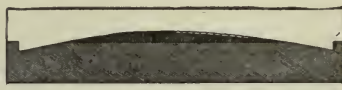


Figure 230. Roadway covered 8 to 12 feet wide with granite blocks, very hard sandstone or blocks made of sand and cement, about 4 x 6 x 12 inches, with 6 x 12-inch surface up, laid on a layer of gravel or sand.

Wide-tire wagons are recognized by the laws in some states as being useful in helping to pack the roadway and keep the surface in a smooth, hard condition. The public can well afford to exempt such wagons from taxation.

Repairing macadam and telford roads.—Here "a stitch in time saves nine" is even more applicable than in the maintenance of earth roads. The great advantage in these roads lies in the hard, smooth surface, which should become still harder and smoother as a result of the wear of travel. If slight depressions are at once filled with crushed rock similar to that forming the surface of the road, these places will soon be worn smooth and uniform with the other portions of the track. If, however, ruts are allowed to remain, each passing wheel drops into the rut, grinding to powder more and more of the rock, and the deeper it cuts the more forcible the blow of the next wheel. Where the rut has become deeper and much of the material has been ground to powder, the dust should be taken out before filling with crushed rock.

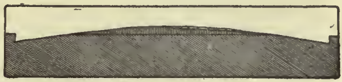


Figure 231. Roadway paved with flat rocks, preferably supported, if on a clay roadbed, with a layer of some inches of gravel or sand.

The raveling or loosening of stones from the surface of the stone road, to be kicked about by passing teams, requires attention, and ofttimes the road roller must be again applied to make the surface more firm. Stones

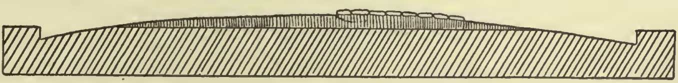


Figure 232. Roadway paved with cobblestones laid on gravel makes a very rough, but very durable, hard roadway.

thus loosened should be removed from the surface, lest wheels striking them cause them to disturb the roadbed. Expensive roads should be patrolled at regular intervals by a laborer who understands the keeping of the road in repair. By having a contract with some resident farmer or laborer, this work can usually be done in wet times when other work is not pressing, and at slight cost to the community.

A badly worn stone road needs its surface reconstructed.—In Figure 236 is shown a road roller in the act of tearing up a macadam roadway. Spikes are placed in the roller wheels in such a manner that the weight of the machine causes them to sink into the hard crust, thoroughly crumbling it. In some cases it

Figure 233. View of steel rails laid for wagon road.

is unnecessary to procure new material for the addition of a layer of surfacing, but the old surface layer may be thoroughly worked over by using the spiked roller to break it up, the common harrow to complete the mixing, and the roller to again thoroughly compact and harden the surface. In case of badly worn roads it will be found necessary to add a new layer a few inches deep, this to be placed on top of the surface of the old material after it has been thoroughly reworked and compacted.

Snow roads.—In the Northern states, where there is a heavy fall of snow, the problem of making snow roads on the right of way, also through adjacent fields, becomes an important part of the year's road work. Where the wind makes hard drifts, it is often necessary to shovel out the roads with hand shovels. Deep level snow can be shoved to the sides and a nice track left by a device made of two planks fastened together in V-shape, and a cross plank to hold the wings apart. Uneven tracks, full of what in New England are called "thank-you-ma'ams," may be smoothed easily by using the reversible road machine or a device especially constructed to tear off the high places and fill in the low ones. Better than either of these methods, however, is the use of the snow roller. In many of the New England states where the snowfall is very heavy the roads are rolled and packed after every storm and no attempt is made to clear a path by plowing. These rollers are pushed over the roads by a number of teams just as the header is pushed through the grain field.

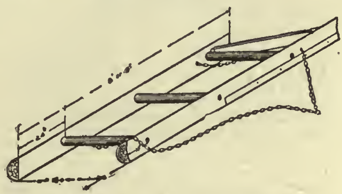


Figure 234. The split log drag.

Bicycle paths.—The popularity of the bicycle as a social fad has passed away; but as a vehicle for practical use it will continue to be an important means of conveyance in many localities. Bicycle paths will not be made in most roadways; hence, where practicable, the wagon road should be so constructed of hard materials that it will make a good bicycle path; but since this is at present generally impracticable, special

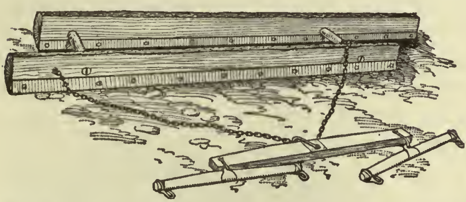


Figure 235. King drag with steel edges bolted on the split logs.

paths may be made for bicycles along many roads. They may be placed between the ditch and the wagon track on wide grades, or on the bank between the ditch and the fence. In some cases it will be necessary to cut and fill so as to avoid excessive grades. However, since these paths must be made cheaply and bicycle riders can walk up an occasional steep place, or by extra exertion overcome steep places, it is not practicable to change the grades as much as in making a track for

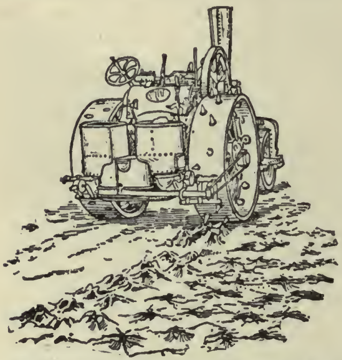


Figure 236. Steam road roller. Spikes in wheel used to break up macadam surface that the broken stone may be remixed, rolled and resurfaced.

wagons. The path can be constructed in a very simple manner. In many cases the sod should be removed and an excavation made a few inches deep. Into this gravel, or better, coal cinders, should be placed, bringing them up even with the sod. This should be thoroughly packed by rolling and on top should be placed fine gravel which in turn should be rolled, making a fine, hard surface. The line of grade should be evened up so as to avoid any sudden depressions or elevations. In crossing roadways, the bicycle path should be constructed with more care, making the hardened surface sufficiently deep and substantial so that wagons will not cut it up. A sidewalk or bicycle path 2 feet wide outside the ditch along a country road may be constructed in several ways: (1) By smoothing the sod and equalizing rough places. (2) By excavating 2 to 4

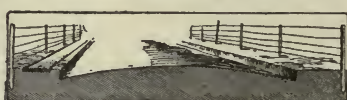


Figure 237. Sidewalk and bicycle path between road ditch and fence.

inches deep and filling with gravel or cinders, using fine gravel for the surface. (3) If the soil is sandy, clay may be mixed with the sand and a thin layer of fine gravel used on top. Placing this walk or path on the grade is not usually practical, because teams will disturb it unless it is protected by the ditch bank.

Lumbermen's ice roads are an important feature of modern lumbering operations in cold regions. In northern Minnesota, for instance, the lumbermen cut out a road from the woods where the trees are felled to the local sawmill or to the lake or river where the logs are to enter the water to be floated to their destination, or to the side of the railway which is to carry them to the lumber mills. These roadways are cleared out and made fairly level before the soil is frozen, or if not made until freezing, they are leveled up by means of snow. Water is then hauled in large tanks and used to sprinkle the surface of the runner track, making it solid ice. These roads are made sufficiently wide so that the horses walk inside the grooves where the sled runners glide on smooth ice. By occasionally going over these roads during the winter with the sprinkling tank, a surface of smooth ice is maintained over which the horses with sharp shoes can draw immense loads of logs at comparatively very small expense per thousand feet.

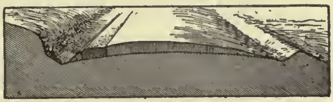


Figure 238. Bicycle path or walk between wheel track and ditch.

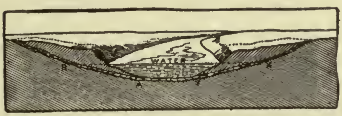


Figure 239. Cross-section of a ford across a creek. Ordinary water level in a stream shown. The dotted lines represent ford graded down and surfaced with stone. In many instances the bed of the stream is solid and the stone surfacing is necessary only at the outer edge of the water, as at R-A or X-Y.

Fords.—Fords are a necessity in pioneer communities, and often remain permanently, both in public highways and in farm roadways. There is no place where a little intelligent work will count for more than in the proper improvement of the roadway by improving the banks of a ford across a stream. At the point where the edge of the water keeps the earth moist there is nearly always a mud hole, or at best deep ruts, through which the wheels of a wagon or buggy must pass. The necessary lift to bring the wheels out of these ruts often greatly limits the load which can be hauled, for "one link determines the strength of the chain." A hard stone surface at this point, if properly placed, transfers the ford from a dreaded place to one which may be passed in comfort and safety. Since it is not wise to build a grade across a stream, as it is likely to be washed out, it is necessary to excavate the bed of the road a foot or less, at the bottom of the stream. This can be filled in with hard materials which will hold up the wheels of the passing vehicles. In many cases coarse gravel will answer very well in the middle of the stream, though broken stones or even flat stones are better. The excavation can be made in warm weather by men and teams working in the water. Where the road leaves the water's edge the banks should be cut down so that there is not too steep a grade, and the cut should be made about a foot lower than the proposed finished grade. This also should then be filled with crushed rock, small stones, coarse gravel, or other material that will not be easily washed about and will form a perfectly hard roadbed. Since fords are nearly always considered temporary expedients, and often are not on the line of legally established roadways, road officers do not feel free to improve them and they are usually left in a very poor condition. A "ford bee," where interested neighbors might spend a summer day "stoning the ford," might do much good to such neglected places. It is an almost unwritten law that public officers can use some public funds, in aiding in these special cases, where the letter of the law would not allow the road officials to take the entire responsibility of the expense of improving a roadway which has not been legally acquired by the public. These ford roads should not be too narrow and should be properly marked by means of tall posts near the ends, so that in times of high water, passers can avoid leaving the line of the grade and getting into the soft earth on either side.

Roadside weeds, if allowed to ripen, are a nuisance to the farm and a nuisance to the public, and withal are obnoxious to an otherwise beautiful country. The public should encourage the farmer to keep the weeds down. As to whether the law should require the farmer to keep the roadside reasonably free from obnoxious plants, or whether the road officials should be required to look after all roads systematically the care of which is not assumed by farmers in growing crops upon them, there is some question. As a rule, public property should be managed in such an exemplary manner that a good example is set for the citizens, and the road officials should be held responsible for keeping the roadway clean of weeds. While the expense would seem considerable, systematic care of the roads by public officials would doubtless pay. If the public would thoroughly assume this responsibility, the roads could be so constructed that banks and grades could be rounded down, seeded to grasses and then be mowed and kept in neat condition by the use of machinery. Since the general advent of wire fences, there is far less excuse for weedy roadsides than when the old-time zig-zag rail fences were common. The use of the mowing machines and a seeding of such grasses as Kentucky blue grass and Bermuda grass will give little chance for weeds.

Roadside trees and hedges add greatly to the beauty of a country, and the public should encourage landowners to plant and care for them. In many instances the public could well afford to have the farmers plant a row of trees several feet from the outer line on the road property, giving the farmer the crop from the trees.

In some countries, as in western Germany, apples and other fruit and nut trees, planted by public officers along the roadway, produce crops of fruit which are sold for nearly enough to pay for the maintenance of the roadway. This might be a practical source of income in some sections in the United States. The crop of fruit or nuts is usually sold by contract before it is ripe, the purchaser harvesting the crop. When our lands become much more valuable, it may be possible for the public to rent the land on the right of way of our broad highways to such an advantage that the renter will not only keep the roadside in a neat manner, but will also help to keep the road in repair. In case of earth roads of heavy clay, trees should not be planted where they will prevent the road surface from drying or cause impassable drifts of snow to form in northern climates.

Relation of farmers to the roads.—The farmer has a special interest in the roads adjacent to and leading from his farm. In some cases, he can unite with the officials in building or draining a road and in making a co-operative drain which will be very useful to his fields. In many cases it is to his interest, as well as to the interest of the public, for the farmer to extend his field operations into the right of way, always leaving sufficient room in the center of the highway for travel. If the farmer will keep the roadside in grass and mow it or pasture it, so as to prevent the growth of weeds, the roadway will be much improved. In some cases, where the road becomes very muddy, the grass border is useful for pedestrians, for bicycles and even for wagons and automobiles. Traveling this roadside is not conducive to a good crop, and people should recognize the interest of a man who takes good care of a roadside and not unnecessarily injure his crops. In many sections of the country, the grasses which are grown do not yield well for more than four or five years, when it is necessary to plow the land and again sow it to grasses and clovers. In this case, the farmer finds it wise to grow one or two crops of grain in rotation with the grass after long intervals, so that he may again seed the grass down with a crop of grain. In many cases our roadways are much wider than necessary and common consent should allow the farmer to use the land within a rod of the center of the road, and in some cases he should be permitted to place his fence nearer the center of the roadway.

Good roads education.—There are many agencies in the United States through which a better knowledge of roads can be disseminated to the people. The largest single agency is the national department of agriculture with its office of public roads, which is doing much to develop a better sentiment among the people concerning the need of good roads and a better knowledge of how to secure these roads in the different sections of the country. The national department is supplemented by the experiment stations and colleges of engineering of each state. Agricultural high schools, where a large number of young men who are to become farmers attend, are well adapted to giving instruction in this line so far as the farmers' interests are concerned. To schools of agricultural engineering in our colleges of agriculture and mechanic arts, and to general engineering schools, however, we must look for trained road engineers, superintendents, contractors and builders. Traveling farmers' institutes, county fairs and the public schools are agencies through which much can be done to disseminate correct ideas on this subject. Practical road engineers are rapidly building up a body of knowledge, and a literature which is helping to place our public road service on a permanent high basis.

Good roads literature.—Printed matter in books, also the agricultural and daily newspapers, contain much information, while bulletins and reports issued by the general government, by the state experiment stations and by the state highway commissions are being multiplied and contain much useful thought on the subject.

Associations such as national and state good road associations, county good road societies, wheelmen's and automobile clubs, both national and state, and the associations of manufacturers of road machines and motor vehicles, all help create an intelligent interest in this subject and help promote the idea of building good roads. As our great country develops its resources it accumulates vast wealth with which it can make permanent improvements. Our highways, being permanent in their nature, are in part the gift of one generation to the next. In many cases the roads should be built and part of the cost left to be paid by future users; but it is highly important that the people at once begin more liberal yearly expenditures in constructing a general system of good roads. The general government, the states, the counties, the cities and all the people should co-operate in this work. This promises to be one of the problems in which the whole people must work together in one long, strong effort. The development of country life demands superior transportation facilities; with this supplied, country life will continue to develop in the United States as nowhere else in the world. More and more our annual increment of wealth should be used in making permanent improvements. Good roads, substantial farm homes, barns, rural schoolhouses and country churches, next to the soil itself, are our permanent country investments. These forms of permanent wealth are not receiving their due attention as compared with city homes, public buildings and structures for trade and commerce.

CHAPTER XII

FENCES

During the last quarter of a century the cost of fencing fields has been greatly reduced by the discovery of new fence materials. Fences have been devised which are much more durable and which will better restrain stock of all kinds than any rail, post, board or hedge fences. The reduced price of wire and the manifold inventions for drawing wire and making it into forms suitable for fences, have brought about an iron age in fence building. A half century ago most of the American farms were fenced with laboriously made stone walls or rail fences, the latter sometimes named worm fences, and aptly called by foreigners "The Yankee zig-zag." Now one can travel across the continent without seeing a newly made fence rail; and in many places the rock crusher is grinding up the stone fences for material with which to macadamize the highways. Iron wire was one of the great aids in opening up the vast prairies of the Mississippi basin for agricultural purposes; it now has a very large influence in promoting the live stock and general agricultural interests. Barbed wires were invented at the proper time to enable the farmers to subdue the great prairies on a scale of extensive farming. Smooth-woven wire has now taken such a practical form and is obtainable at such reasonable prices that more comprehensive field and farm management, with live stock as a leading feature, is being inaugurated as the permanent system of management on American farms. Nowhere is there such an opportunity for carrying out the broad principles of scientific farm management as on American farms, and nowhere else is there such a comprehensive plan of combined farming and homemaking, nowhere else such a great, rising race of farmers. The wire fence stands with the modern railway, the plow, the cultivator, the reaper and the thresher as a large factor in promoting our extensive and prosperous agriculture and the unsurpassed country life of our American family farms.

The great variety of materials and uses, also the varying conditions under which fences are built, give the farmer the opportunity to exercise considerable ingenuity in devising structures to best meet his needs. The fence should efficiently do its work, be easily kept in repair, and economical of construction, enduring if may be, good to look upon or at least not conspicuously offensive to the eye.

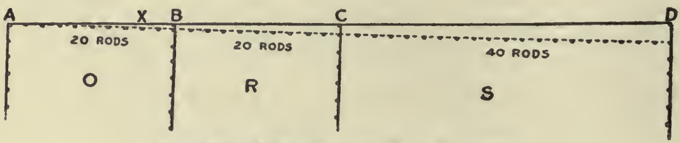


Figure 240. Fence line placed in the wrong place.

The first step in building a fence is to secure the exact location desired throughout the entire line of the fence. Where practicable, the two points where the fence is to end should be located with care, and the fence line laid out on a line between them. Thus, in Figure 240, the corners of the farm, A and D, should be first established and the fence line staked off in a straight line between. If first in fencing field O a slight error is made in placing the corner at B, and the fence line thus established is projected forward in a straight line to D, the error will have been multiplied, placing one-eighth of an acre on the wrong side of the fence.

If a post and wire fence is to be built the planting and bracing of corner and end posts is a matter of most careful consideration. If the wires, or ribbons of wires, can be attached to an unyielding post at the corner, they do not sag, and they serve to hold all the other posts in line. These end posts need to be planted deeply in the ground and thoroughly anchored by cross pieces fastened to their bottoms and braced, as with a rather long timber, 10 to 14 feet, reaching some distance along the line of the fence, and placed at not too wide

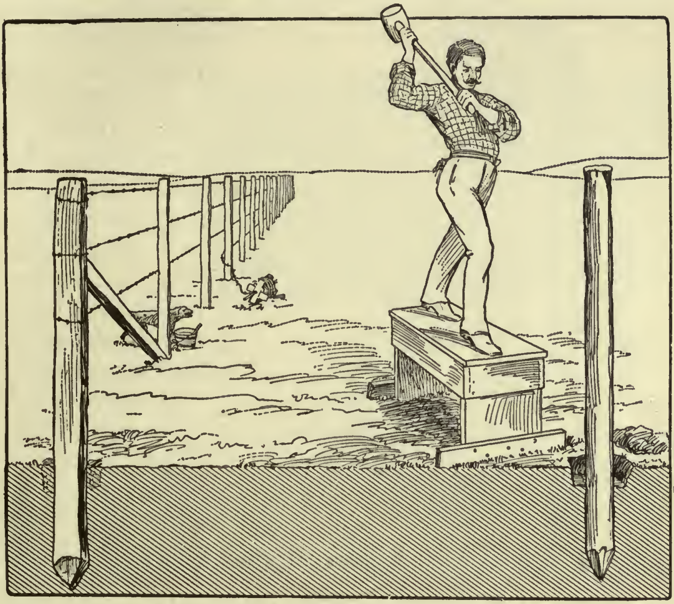


Figure 241. Driving sharpened fence posts with sledge and stand.

an angle with the horizontal, so as to avoid pulling the corner posts out of the ground.

The line posts for wire need not be placed so deep in the ground nor set so firmly as is necessary in the case of wooden fences. This is particularly true in the case of barbed wire, since animals do not rub against the wires so much as against wooden fences. The winds do not blow wire fences down, and animals running into them do not press against a single post, but the strain is equalized among several along the line. Reel devices are very useful in distributing and rolling up a single strand of barbed wire, and rolls of wire fence ribbons.

Setting posts.—The old art of digging post holes with a spade, setting the posts in line and tamping the returned earth solidly about them is hard work. But even here there is opportunity for system in cutting the sod, in pulverizing the soil in the bottom of the hole, and in lifting out the spadefuls of earth. Some men will quickly dig a post hole with half the expenditure of energy required by another who has not learned how to handle the spade to the best advantage. It is difficult to give instructions without a spade and a place to make a post hole. Post-hole augers and some other form of implements for digging post holes save much labor. In many cases the best way to set posts is to sharpen them with a sharp ax, dig the holes one spade length deep and then drive the posts with a heavy maul or sledge. The workman can stand in the back end of a wagon, or better, on an especially con-

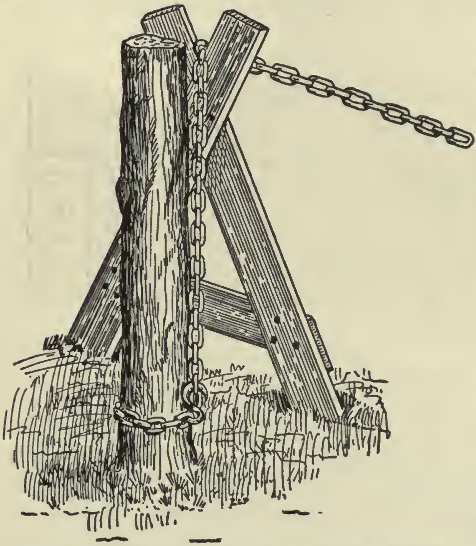


Figure 242. Device for pulling fence posts with the aid of a team.

structed bench, and drive the posts to a depth of 2 or 2½ feet. Especially where the fence is temporary is it worth while to sharpen the posts that they may thus easily be driven when set in the new location. Where the post is not sharpened it is important that the earth be tamped very firmly about the bottom of the post and also at the top of the hole so that it will be held firmly. Pulling posts with a horse, chain and simple lever avoids heavy lifting. (See Figure 242.) With suitable tools for withdrawing or breaking the staples, with a handy device for rolling up the wires and again unrolling them along the new line, and with good wire stretchers, any wire fences can be moved at a cost of only a few cents' worth of labor per rod

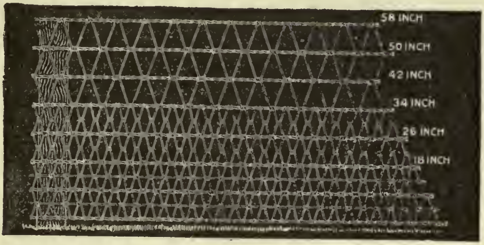


Figure 243. Woven wire fence for horses, cattle, sheep and swine.

Repairing fences.—An occasional inspection of wire fences with hammer, nails, staples, small pieces of wire, and wire stretcher at hand will avoid loss from injury to fences, injury to crops and often avoid trouble with neighbors, and sometimes prevent great injury to animals. A fence is like any other structure: it is likely to get out of repair, and when in such condition it should be repaired at once, as nowhere else does the "stitch in time save nine" to better advantage.

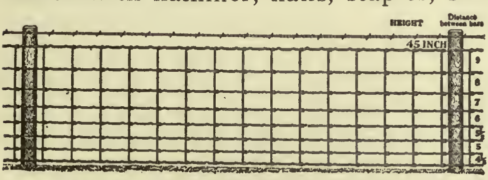


Figure 244. Woven ribbon with only one barbed wire above.

Barbed wire fences.—For cattle, sheep and swine, barbed wire strung on posts from one to two rods apart makes a cheap and most effective fence, and for very large pastures barbed wire is fairly well suited for retaining horses. There has been a great deal of criticism of barbed wire fences, the larger part of which is uncalled for. Many critics who have seen only the sentimental phase of the question have insisted that it is cruel to inclose animals by a fence which is liable, accidentally, to make wounds and cause pain. Barbed wire fences may occasionally injure horses so that they become less salable, and sometimes even cripple them. Barbs often slightly injure the skin of cattle, reducing its value for leather. But when we put against these objections the immense saving in the cost of barbed wire fencing as compared with other forms of fences, the smaller expense of keeping them in repair and their greater effectiveness over most other kinds of fences in restraining animals, the barbed wire has the advantage for many purposes. It is safe to say that more animals are injured and suffer from breaking through wooden fences and gaining access to crops of grain or very succulent crops; from getting out of place and being chased by dogs, than from any injuries or cuts due to barbed wire cuts. With properly built wire fences stock quietly submit to their confinement and feed much more contentedly and profitably than when they are surrounded by fences which they are constantly trying to rub down or climb over.

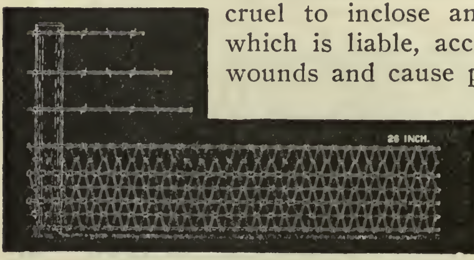


Figure 245. Hog and cattle fence; 26-inch smooth wire hog ribbon, with three barbed wires above.

Woven wire fences are manufactured by many firms and sold through their local dealers in large rolls of 20, 30 and 40 rods. Smooth, and also barbed, wire fences may be made up for cattle or horses alone, in which case the lower wire is a foot or more from the ground; while fences reaching to the ground are suitable for restraining hogs and sheep as well as the larger animals. Barbed and smooth wires may be combined, and in many cases this is an economical arrangement, especially in making fences which are to restrain both large and small animals. With barbed wire, smooth wire, or even with smooth and barbed combined, fences may be woven at the time it is tacked on to the posts by machinery devised for that purpose.

The three-wire barbed fence (Figure 248) is one of the large factors in American cattle raising. It costs about ten cents per rod for iron, ten cents for posts and a few cents for labor. The wires last more than a

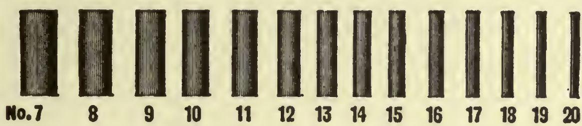


Figure 246. Actual size of wires by numbers, 7 to 20.

quarter of a century, and good posts more than ten years. The annual expense for repairs is very light. The interest account and the maintenance account are very small, and if occasionally inspected and repaired, this fence is very secure for the larger animals. The posts are usually sharpened and driven with a heavy sledge in the hands of a man standing on a sledge stool.

Wooden fences.—Board fences were very much in use a few decades ago, but are now very rapidly giving way to wire. Fences made of 6-inch pine boards are very satisfactory when new, but the boards become brittle and are not safe. Tight board fences are entirely too expensive for fencing, unless in exceptional situations, as about small paddocks near the barns, and even here heavy woven wire is better, except where tight fences are especially needed to serve as protection from cold winds. Rails and poles in the place of boards serve the purpose of the pioneer with whom the poles are sometimes more easily procured than the money with which to purchase wire. Thus, tamarack poles often serve a good purpose in wooded districts, as do also poles from the quickly grown willow and other trees in the prairie regions. But fences made in this way are short lived, and, at the best, are not nearly so safe as are wire fences. The old-fashioned rail fences are made up in a number of different ways, but cannot be classed as very satisfactory fences. They are often blown down by heavy winds, are rubbed down by cattle, require considerable labor to keep them in repair, and are not very durable.

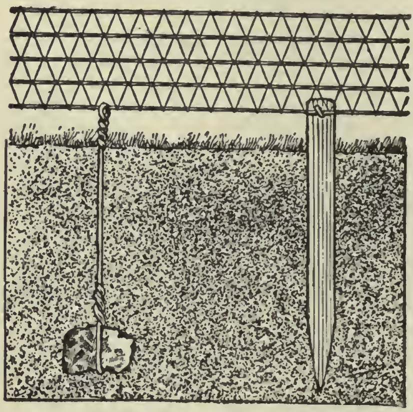


Figure 247. Anchoring fence ribbon between posts makes it possible to use fewer posts.

Hedge fences have been much used in mild climates, as in England and in some of the middle and Southern states, but they have almost dropped out of use for field fences, and wire is supplanting them. They add much to the beauty of the landscape if kept in repair and travelers think they add much to the country, but they are usually poor field fences. Where a portion of a hedge dies out animals can pass through the gap; besides, gaps soon make a fence look ragged and weak. Very many of the hedges in beautiful England, where they are valued for their landscape effect, are mere weeds encumbering the ground. Either a wire fence must be placed alongside them, or else the fence must be used in a patched-up way that makes it anything but efficient in restraining animals and far short of attractive. Besides, in the end, they are nearly always expensive, since the labor of caring for them is considerable. In many cases part of the plants die out and form harbors for weeds. They

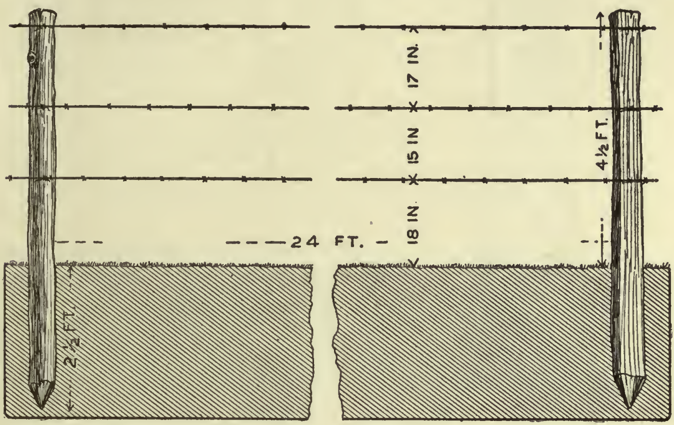


Figure 248. Three-wire barbed cattle fence.

require some land, and take some fertility from the adjoining fields into which they spread their roots. Hedges should be used much more for ornament on the farmstead, but less for field fences, especially less for fencing against live stock. Many theoretical propositions have been presented to the American farmers by designing hedge-fence companies and nurserymen who desire to sell hedge plants; but nothing practical comes out of these propositions. A hedge costs more to plant and care for until large enough to serve as a fence than the price of a wire fence. Besides, a wire fence is necessary to protect the hedge and restrain the animals while the hedge is passing through the first few years of its growth. There are particular places where a hedge is useful as an ornament as well as to serve as a fence, and the purposes of ornamentation may properly be combined with the useful about the farmstead. In some cases growing willows, or other trees, may serve as posts to which wire fencing may be attached, thus in part serving as a hedge. But, as a rule, the better way is to purchase posts or grow the posts in the forest plantation in the farmstead or on a separate part of the farm, or use reinforced cement posts, and then make simple post and wire fences.

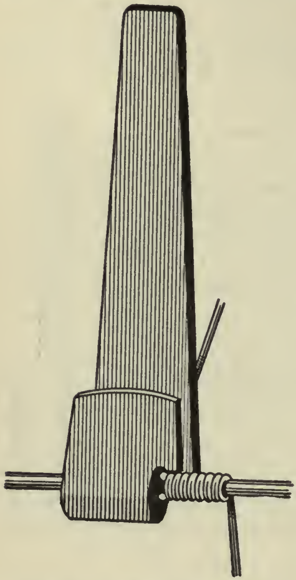


Figure 249. Tool for splicing wires.

Stone fences were much used in the earlier times to inclose those fields which supplied an abundance of this kind of fencing material, but unless the stones are of such form and size that they can be so laid that the fence can stand long without repairing, this kind of fence is expensive to construct and costly to keep in repair. As a rule, it is economy, even where stones are abundant, to collect them into piles neatly laid up, and use posts and wire for fences. Unless stones are very abundant on the farm, or in the neighborhood, there will be other and more practical uses for them.

Paddock fences.—Within the farmstead special fences are needed. Stronger fences are required for keeping animals closely confined than for keeping them on a larger range. Barbed wire is objectionable for the paddock fences, because in the small lots where many animals may be confined there is danger of the younger, weaker or more timid animals being crowded into the fence and injured. Until recently the problem of paddock fences was a hard one, but the advent of heavy woven wire offers a complete and satisfactory solution. Ribbons made of wire of medium weight, and of light poultry wire, may be purchased nowadays at very reasonable prices. It is not wise to use wire of too small a diameter in paddock fences, or even for poultry yards, because small wires sooner rust so as to break. Properly galvanized wire is more durable than painted wire. Heavy woven wire ribbons are sold which will not easily be rubbed down by strong cattle when closely confined.

Fences made by nailing boards horizontally on posts, or running stringers on the posts and nailing on the boards in a vertical position, are expensive and not very durable. However, if no other protection from winds can be afforded in a yard, the tight board fence has an important use. In stony sections the exposed side of the lot may be protected by a stone wall. Such walls are much more satisfactory if they are built up with mortar, but a very good wall may be built without mortar if the base stones are well laid and the wall built high enough to keep the animals from knocking off the top stones.

Woven wire for paddock fences should not only be higher and heavier than that used for field fences, but the horizontal and vertical wires should both be woven closely together. A good plan is to have the strands woven the same as poultry fence, only using heavier material. Strong, durable posts should be firmly set not over 16 feet apart, and great care must be exercised to get the corner and gate posts securely anchored and braced.

Hurdles or portable fences are useful in caring for small flocks of sheep, young pigs, calves or young chicks

Figure 250. Light portable fence used in pasturing sheep. One piece 1 x 6 and three 1 x 4, 16 feet long, for horizontal bars; three pieces 1 x 4, 42 inches long, for uprights; one piece 1 x 6, 42 inches long, and two 1 x 4, 60 inches long, for braces.

when on the pasture. By means of hurdles the animals may be moved frequently, giving them a constant supply of fresh feed. Hurdles can be made of boards, wires

Figure 251. A beautiful experiment at Minnesota Agricultural College. Numerous well-trimmed hedges growing side by side.

and boards, or wires and slats, some form of device for holding the hurdle up being adapted to each kind of hurdle. Where areas to be fenced are of considerable size, movable barbed wire or woven wire fencing to be attached to posts, is cheap and easily adapted to the purpose. Pastures of annual crops, or shift pastures, as pasturing the stubble after a crop of grain, may be surrounded by temporary fences. The cost of moving fences is often less than the loss sustained by allowing stock to remain in pastures which are short of feed

Figure 252. Buckthorn hedge beside roadway.

while in the adjoining field some green crop is going to waste.

Ornamental fences.—On the farm, fences designed to be ornamental should be rather plain and substantial, not necessarily expensive, and should be of a kind easily kept in repair. Iron fencing of a plain, strong design makes a fence pleasing to the eye and quite durable.

Some of the forms of smooth woven wire fencing are so made up as to be very inconspicuous, a really excellent feature, as heavy fences hide the beauty of the trees, shrubs and open lawn. Wire-and-picket fencing is usually not so desirable, as it is heavy and difficult to keep from sagging. The slats add no beauty and the fence is not as durable nor has it as pretty an effect as a fence of smooth galvanized wire.. Strongly built woven wire fences serve to run vines on, often with

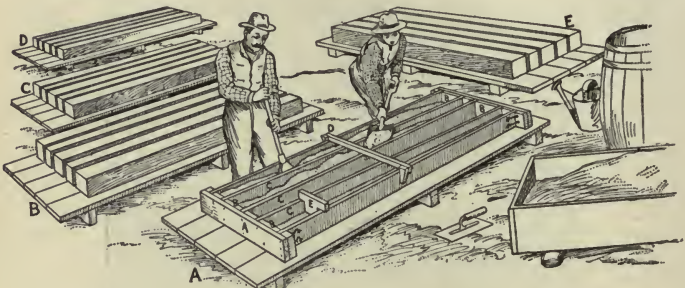


Figure 253. A, mold for making posts 7 feet long, 5 x 5 inches at the bottom and 3 x 5 at the top; also mortar box, shovel, tamping rod and gauge for leveling the first layer of tamped mortar preparatory to putting in the first two wire cables; a, ends; b, dividing blocks; c, division boards; d, outer tie; e, leveler. B, C, D, pallets each with five posts, 7 feet 5 inches by 5 inches and 5 inches by 3 inches, from which the molds have been lifted as left to cure. E, pallet with five posts, 7 feet 6 inches by 6 inches and 6 inches by 4 inches. Molds for posts of different lengths and diameters may be used on the same pallets; thus, posts 6 feet long, 4 x 4 inches, 3 x 3 inches; posts 8 feet, 6 x 6 inches, 6 x 4 inches, etc. (After P. L. Wormley, Farmers' Bul., U. S. Dept. Agr.)

most attractive effect. Where stones are abundant and can be built into a fence, a very pretty effect can be produced about a lawn, especially as they serve to train Virginia creepers or other vines. Where a retaining wall and fence combined are needed, a handsome fence can be produced by combining these features. In some cases, a wire fence can be added above to reinforce the low stone wall, much reducing the expense and yet combining beauty and utility. Too little has been done to embellish the immediate surroundings of the average American farm home. There is no part of the United States, unless in those sections in which the rainfall is too deficient, that we do not have shrubs suitable for making a low handsome hedge. The Buckthorn, for example, endures the severest winters of the northern parts of Minnesota and Dakota. The experiment farms of Brandon and Indian Head, Canada, North of Dakota and Montana, have abundantly demonstrated that beautiful hedges can be grown far north and far

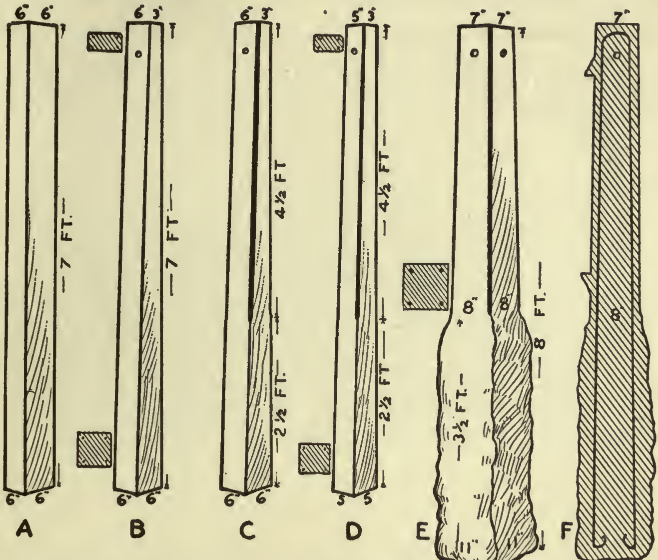


Figure 254. **A, 7-foot concrete post, 6 x 6 throughout;** B, 7-foot, 6 x 6 at bottom and 6 x 3 at top, hole near top for wire loop to hold staple strip, cross-sections of ends of B showing positions of twisted wire reinforcements; C, 7-foot, 6 x 6 at bottom, 6 x 3 at top, corners rounded; D, 7-foot, 5 x 5 at bottom, 5 x 3 at top, cross-sections of ends of D; E, corner post molded in place, underground part 11 x 11, above ground part 8 x 8 at bottom and 7 x 7 at top, length 8 feet, holes near top in both directions, cross-section of E at ground line showing four two-wire cables; F, cross-section of corner post showing lugs molded to hold braces; also wire or steel rod reinforcement.

out into the dry plains country. As we proceed southward, the number that are hardy is increased. Among those plants making a pretty and at the same time durable hedge are the Buckthorn, Buffaloberry, Red Cedar, White Cedar or Arbor Vitæ, Russian Mulberry and many others equally pretty, but less practical and hardy.

Wooden ornamental fences still have their place, though much restricted by the use of the cheaper, more durable wire fences now available for inclosing lawns. There is hardly an excuse remaining for inclosing country lawns, school grounds, church yards or cemeteries with a board fence, which will rapidly decay, and at best is not a thing of beauty. Plain woven-wire fencing can be used for most of these fences. Where it is desirable to obscure from view objectionable features this can be done by training Virginia creepers, English ivy, wild grapes or other vines on fences.

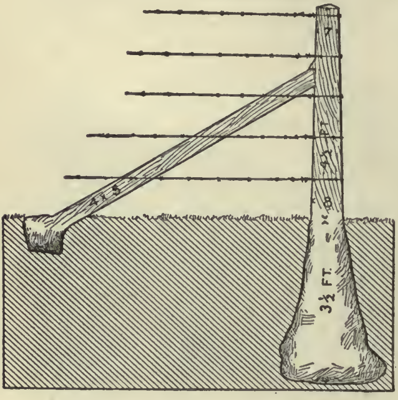


Figure 255. Corner post built in place with base tamped in hole enlarged at bottom, and cement brace set with enlarged end molded in place. Both post and brace are reinforced with double twisted wires.

In making a landscape by means of trees, shrubs, lawn grasses and other living forms, the modern wire fence enables us to have an inclosure without obstructing the view, or by growing vines on it we can frame the picture or otherwise make it ornamental. (See Figures 251-252.)

Poultry fences.—For inclosing yards or small fields for poultry, woven wire is by far the most satisfactory of all forms of fencing. In some places, as between small inclosures, it is necessary to place boards at the bottom to a height of 2 feet to prevent cocks from fighting. For outside fences, bottom boards are not necessary, and rather strong woven-wire fencing, with 1 or 2-inch mesh, may be used. For temporary purposes light poultry fencing can be utilized, though it is not substantial and is not so easily moved to new posts as the ribbons of heavier wire. The latter kind of fencing is more easily kept from sagging and is more durable. The boards at the bottom of the fence can easily be renewed when too much decayed to be of further use. Sections of woven wire attached to rectangular frames, say 2 by 6 feet, made up like hurdles, are exceedingly useful in caring for broods of young chicks which have been hatched in incubators and are raised in artificial

Figure 256. Filling the mold with cement after the wires have been placed inside. Hole left for the end of the brace mold.

brooders. Some of these may be used as covers of small yards to inclose hens with their broods.

Posts.—Few posts have been used of other material than wood, but there is a rising demand for a more durable material. While wooden posts do not last many years, they have been so much cheaper than either iron posts or cement posts that their use has generally been the most economical. For lawn fences, iron or cement are in some cases more practical than wood, and in a few cases stone may be utilized to advantage. White oak, white cedar and red cedar are prized because they will last many years, while posts of such species of trees as tamarack, basswood and white willow last only a few

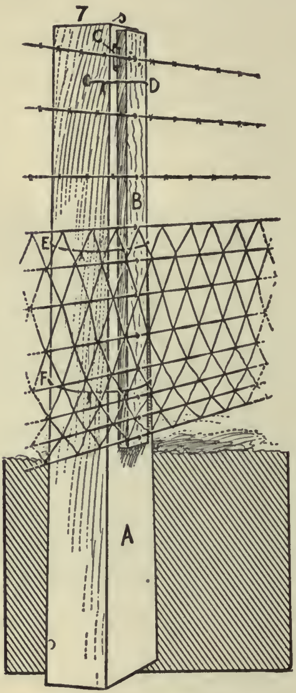


Figure 257. A, cement post; B, wooden stay on face of post to which wires are stapled; C, block set in groove in face of post to hold stay from being pushed up or down. D, hole near top of post to receive wire holding upper end of stay firmly in place; E and F, wires about post to hold stay in place. Woven ribbon at base. Barbed wires above.

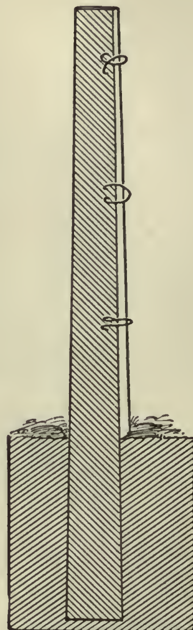


Figure 258. Wire loops sticking out of the face of the posts. No. 7 galvanized wire is suitable. They can be placed vertical or horizontal, owing to method of fastening wire fencing to them.

years. Wooden posts are so easily replaced in wire fences and the top is still useful for fuel, that very poor wood in the end is not very expensive.

Cement posts.—Posts made of cement and reinforced by steel are destined to rise in favor with the increase in the price of wooden posts. Especially for end posts of permanent fences will it pay to use reinforced cement, and in many permanent fences line posts of these materials are in the end more profitable than posts of wood or other material. If well made, they grow strong with age; the cement not only increasing in strength with age, but also protecting the steel from rusting. Line posts are ordinarily quite strong enough if reinforced by placing in each corner a cable of two wires, twisted together, of the same size as that used in double barbed wire, No. 11 or No. 12, or even ordinary new barbed wire may be used, weighing rather less than two pounds for the four cables.

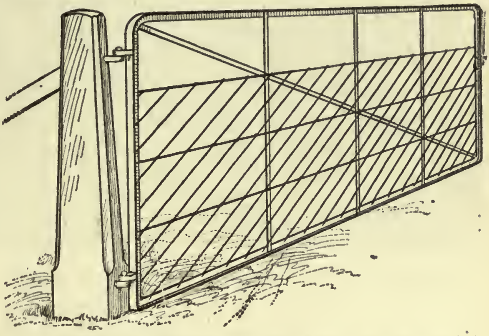


Figure 259. Cement corner post carrying an iron gate.

Unless extra strength is required a suitable size for line posts is 6 x 6 or 5 x 7 inches at the base, and in either case 3 x 6 inches at the

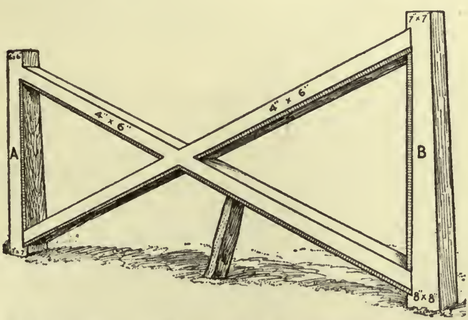


Figure 260. Cement corner post, B, and brace post, A, with diagonal cement cross braces constructed in place. Forms should remain in place for at least a week.

Figure 261. Stretching a ribbon of woven wire to attach it to a corner post.

top and 7 feet long. Where strong posts are required the base can be made 6 x 8 inches and the tops 3 by 6. Shorter and longer posts, also with lesser or greater diameter, will fit particular conditions. With cement costing $2 per barrel, sand and gravel 50 cents per cubic yard, wire cable 6 cents per post, and labor 20 cents per hour, and allowing for cost of molds and miscellaneous expenses, the cost of the smaller of these posts should be rather more than 25 cents and the larger ones about 35 cents apiece. Corner posts 6 to 8 inches square, with two more wire cables, or rods, in the corners, will cost two to five times as much as line posts, and 4 x 4 or 4 x 6-inch

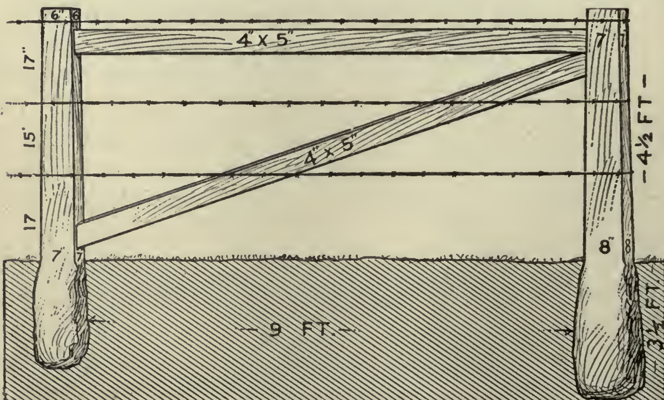


Figure 262. Cement corner posts and braces molded in place.

Figure 263. Cement corner post and braces, all made in place, for woven wire fence.

braces, 8 to 10 feet long, will cost 30 to 50 cents apiece. Cement corner posts with a large lower end, as in Figure 255, are very awkward to remove when broken and the amount of cement required is large. Made with straight sides, or with rough and slightly enlarged lower end, corner posts will serve their purpose quite as well and

Figure 264. Well-braced cement corner post and cement line posts.

will cost less. Cement posts, unlike cement blocks, cannot well be made in a machine and carried aside on panels, because the pallets bend and the posts crack, perhaps only sufficient to allow air in to rust the reinforcing wires. The pallets for line fences should remain in place until the post hardens, the sides and ends of the forms to be used in succession on stationary bases. Narrow, three-cornered strips of wood are sometimes laid lengthwise in the corners of the mold, so as to round the corners of the post, but as the downward face of the post is the one to which the wire fencing is attached this is not very important. The upper corners can be rounded with a trowel, if the mixture is not too wet. Painting the insides of the molds with soap is often wise. Four inches from the top of the post, make a transverse groove in the back of the post near its top to hold in place a wire which binds a staple board to the post; or, 8 inches below the top, lay horizontally a corn cob, a piece of

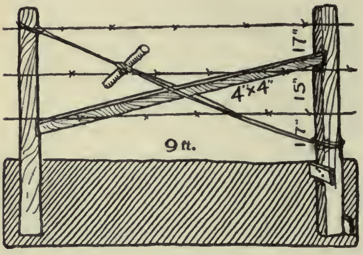


Figure 265. One of the very best systems of bracing wooden end posts.

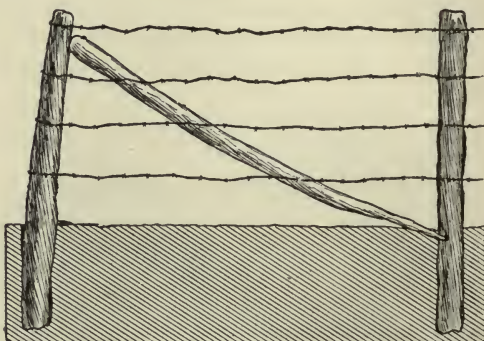


Figure 266. Poor method of bracing corner posts.

sumach wood, with large pith, or other material through which a wire can be punched, or a piece of soft wood, which can be driven out, and thus provide a hole through the center of the post for the stay binder. (See Figure 254.)

Wire loops can also be inserted in the surface of the finished post before it hardens, to serve as attachments for the fencing. (See Figure 258.) In molding the posts, fill in mortar and work, or tamp, and dress down with the deep leveler shown in Figure 253.

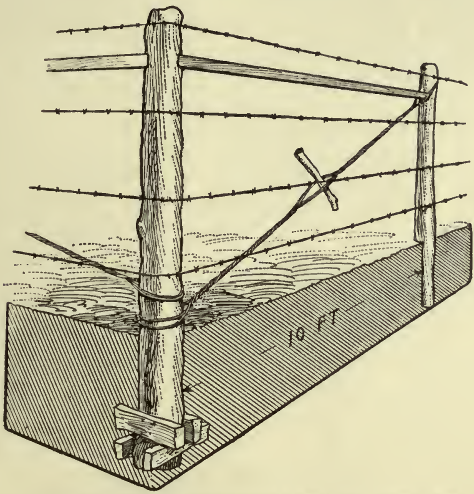


Figure 267. Good method of bracing wooden corner posts

The apparatus used in making cement posts is simple and inexpensive, as shown in Figure 253, A, B, C, D and E.

Posts can be made of cement and any sharp, clean sand in the proportion of *one* to *three*. But where gravel about one-half inch in diameter, or broken stone of the same size is used, the posts will be both stronger and cheaper, using *one part cement, two and one-half*

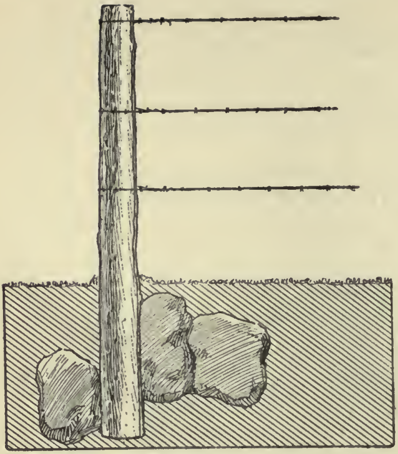


Figure 268.

parts sand and five parts gravel or stone. The cement and other materials can be measured by means of bottomless boxes set in the mortar box. The cement and sand should be thoroughly mixed dry; a "crater" should be made in the pile, the water poured in, the edges of the crater worked into the water and then the whole worked and shoveled over until thoroughly mixed. The mortar can then be spread out level and the gravel or crushed stone can be spread on evenly and the whole well mixed by shoveling over until uniform. Using a "dry mix," which "must be tamped for some time before water shows on the surface," is not so satisfactory as a "moist mix" which "requires only a little tamping to bring moisture to its surface," or a "wet mix," which "can be poured" and "only needs to be worked about till it fills all crevasses." The reinforcing wires are retained in position with some difficulty if a too dry mix is used, and are liable to be forced so close to the corners that

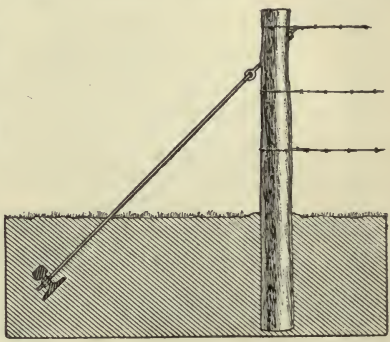


Figure 269.

slight chipping or transverse checking of the post will cause them to be exposed. Some experimenting will be necessary to learn the best proportions and the best manner of mixing each class of materials found available in a given neighborhood.

Lay, in each of the two lower corners, a cable of two wires, twisted together and nearly as long as the post, less than an inch from the sides and less than an inch from the face of the post. Again fill in and work or tamp, and then dress down with the shallow leveler, similar to E but shallower, to about three-quarters of an inch from the top. Place the other two cables in the upper corner, less than an inch from the sides. Add the upper layer, dressing it down level with the side boards. Leave the forms in place for two days to allow the mortar to set, when the sides and ends can be drawn to serve again on other pallets, using care not to disturb the posts. The dividing strips between the posts should remain a week, as removing them earlier disturbs the posts. The posts should lay several weeks, or better, some months, without disturbance. Frequent

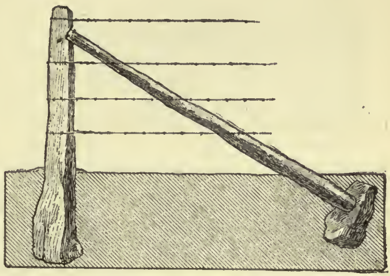


Figure 270.

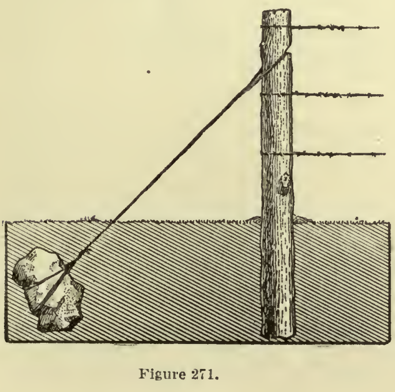


Figure 271.

wetting down is useful to secure the best curing. In placing the posts on the wagon, care should be used not to crack them so as to let air in to cause the wires to rust off.

Corner posts can usually best be made in place. The post hole should be rather large and deep, the bottom

Figure 272. Common three-board slide gate in three-barbed wire fence. This is the most widely used American cattle fence and gate.

larger than the upper end, and a hole 10 or more feet away should be made for the foot of the brace. The mold of the post and the mold of the brace should be put in place, and the concrete placed in them and worked

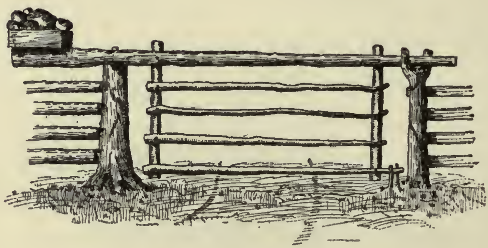


Figure 273. Rustic and serviceable pioneer gate.

down or tamped. Some care will be needed to keep the two or more double twisted wire cables upright and in place in each outer corner of the upright post. The post should stand some months before a heavy fence is strained upon it. (See Figures 259 to 264.)

Where a brace post and cement cross braces are used they can easily be built in place. Care must be used in having stiff temporary wooden supports under the long braces, and if of boards, they must be supported from below or by means of nails through the side pieces of the molding form. (See Figures 260 and 261.)

Figure 266 shows a poor method of bracing corner posts in which only one brace is used. The corner post is easily loosened causing a sag in the wires. The lower end of the brace being too low tends to lift the corner post out of the ground. If placed higher without the wire from the top of the first line post to the bottom of the corner post the line post is often pushed over, thus allowing the corner post to follow the line post and thus loosen the wire.

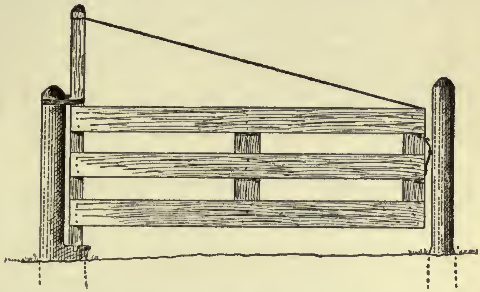


Figure 274. Splendid swing gate. May be constructed of three, four or more horizontal boards.

Bracing corner posts.—Where a single brace is used it should not be too slanting lest the strain from the wires, due to changing temperatures, causing the wires to lengthen and shorten, pull the post out of the ground. The plan of bracing wooden posts shown in Figure 265, is both cheap and effective. The two blocks on the post, one at

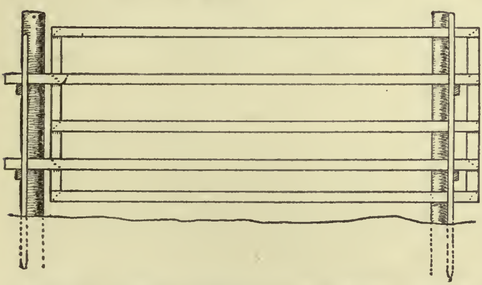


Figure 275. Western slide gate. Cheap, simple, serviceable and durable; fairly convenient.

the bottom on the far side and one near the surface of the ground, help the post to hold its load. The twisted diagonal wire prevents the brace post giving way, and thus the brace is held in place and keeps the corner post from responding to the pull of the wires. In starting to erect a wire fence, the planting and brac-

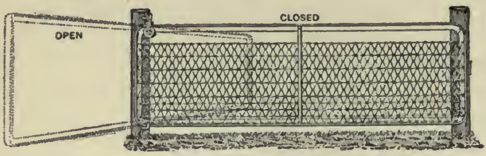


Figure 276. Steel slide gate, made of angle iron and woven wire.

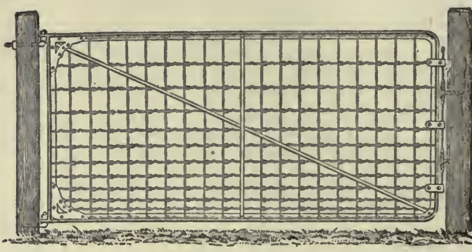


Figure 277. Single hinged drive gate of angle iron and woven wire.

ing of corner and end posts is a matter of most careful consideration. If the wires, or ribbons of wires, can be attached to an unyielding post at the corner they do not sag and serve to hold all the other posts in line. These end posts need to be planted deeply in the ground and thoroughly

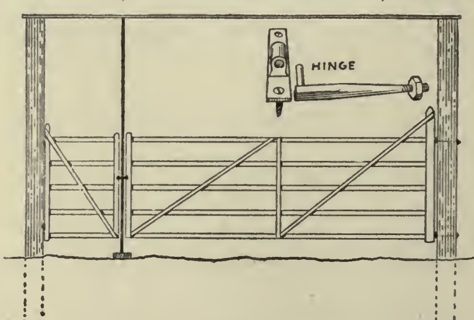


Figure 278. A large, wide gate better adapted for an entrance to the farm than for a common pasture or lane gate.

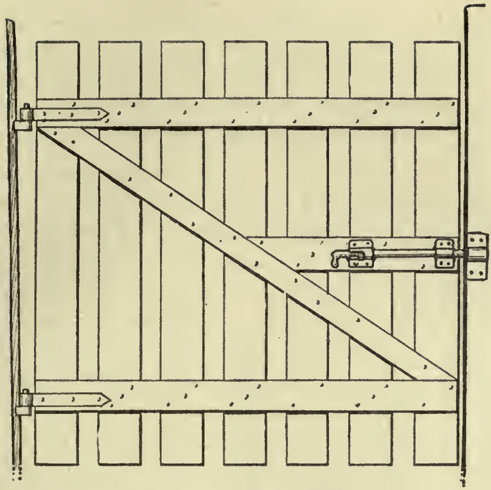


Figure 279. Paddock gate made of 2 x 4 pieces.

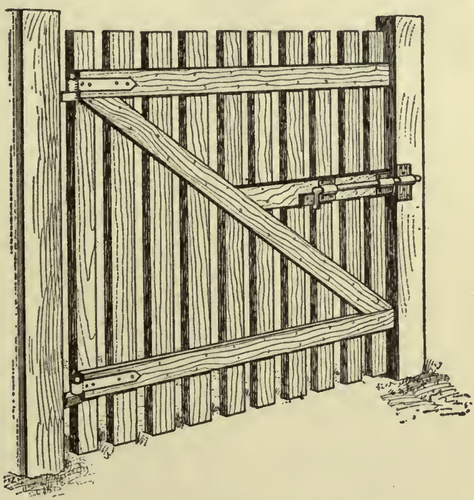


Figure 280. Heavy paddock gate.

anchored by cross pieces fastened to their bottoms and braced, as with a rather long timber, 10 to 14 feet, reaching some distance along the line of the fence, and placed at not too wide an angle with the horizontal, so as to avoid pulling the corner post out of the ground.

Gates.—Gate devices for fences are very numerous and the patent office at Washington has very many applications for letters of patent for special patterns on gates. Since simplicity is one of the first necessities in a gate, complicated forms have not become popular, and the styles of gates most in use are of exceedingly simple construction. A number of forms which have proven very useful are here illustrated. Since iron and wire are so much more durable and strong, and easily handled, gates made of gas pipe, or better, of angle iron and woven wire, or other forms of iron, should take the place of wooden gates in many situations. Where gates are not much used, combined wood and wire-hinged gates, and wood and iron sliding gates, answer every purpose, and have the great advantage of being easily made and easily repaired. Rustic gates, as in Figure 273, may be made pretty; and gates of iron as inconspicuous and therefore not out of harmony with other features in making up a pretty landscape.

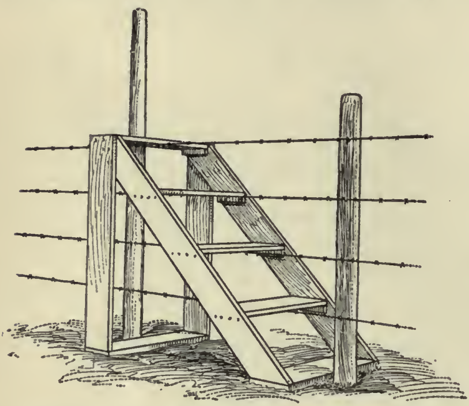


Figure 281. Stile across a wire fence; wires should be wrapped with cloth to avoid tearing clothing.

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