THE

SOIL OF THE FARM

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PUBLISHERS' PREFACE.

The improvement of the soil by drainage and irrigation, and by liming—the maintenance of its fertility by the operation of our tillage implements—its exhaustion by cropping, and its restoration by manuring—are the proper subjects of these pages. The resources of the farmer, in the economy of home manures and in the use of manufactured and imported fertilizers, are considered in detail.

Fertility of course depends not only on the soil but on the climate. And it is on the fitness of the circumstances in both these particulars that the luxuriance and prosperity of plant growth rest. The principles on which fertility is dependent may be the same in all climates. The capability of obtaining from soil and air the building material of the growing plant is everywhere its limit, but it is the climate alone which determines the vegetation in which the fertility is exhibited.

Messrs. J. B. Lawes, J. C. Morton, John Scott, and George Thurber, so eminent in their fields of labor, are the writers of these valuable pages.

May, 1883.

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CHAPTER I.

ORIGIN AND FORMATION OF SOILS.

Soil and Subsoil—Conversion of Rock into Soil—Processes of Weathering and Denudation—Alluvium—Boulder Clay—Vegetable Mould—Peat.

Soil and Subsoil.—The soil is that part of the ground which can be tilled and in which plants grow. It is merely the upper stratum of decayed rock mixed with vegetable and animal remains. It varies in depth from less than three inches to more than a foot.

Immediately below the soil is the subsoil, which rests upon underlying rock. The subsoil is generally more compact than the soil, being less stirred in cultivation; and it is frequently of a different color. The principal difference, however, between the two consists in the greater amount of the organic matter in the latter, which is generally present to some extent in both.

The main distinction between the soil, the subsoil, and the underlying rock consists in this, that soil is rotted subsoil and subsoil is rotting rock. A vertical section of the soil will generally show several gradations. The whole may be made up of five different layers. There will be: (1) A grass layer; (2) A vegetable soil layer; (3)

Soil or rotted subsoil; (4) Subsoil or rotting rock; (5) Underlying rock.

Conversion of Rock into Soil.—Various forces are active in this work. (1.) The atmosphere acts chemically upon rock; its action consisting chiefly in the oxidation of those minerals which can contain more oxygen, and in the production of carbonates and bicarbonates, whose solubility still further aids disintegration. (2.) Changes of temperature have a loosening influence upon rocks, by causing alternate expansion and contraction. We see its effects in the way in which, after a strong frost, the soil of fields and the material of roads is found to be loosened and pulverized. (3.) Rain acts both chemically and mechanically in the same direction. Its chemical action arises chiefly from the solvent power of the carbonic acid which it absorbs from the atmosphere, and which acts especially upon rocks containing lime; partly, also, from its oxygen combining with substances not yet fully oxidized. Its mechanical action appears in the way in which it washes off the finer particles of disintegrated rock or soil from higher to lower ground. (4.) Plants promote the process of converting rocks into soil, both in their growth and in their decay. Growing plants keep the mineral matters, amidst which they grow, moist, and enable water to penetrate and rot them; while their roots exercise a double effect, inserting themselves into joints and crevices, and thereby causing fragments to be detached, dissolving also and then absorbing minute portions of the rock fragments. The action of decaying vegetable matter is still greater. It absorbs much moisture and keeps all bodies around it damp; it is constantly yielding carbonic acid, which, being absorbed by the rain water, is carried down through the soil and then acts powerfully upon mineral matters below. Certain organic acids are also produced during decay, and these and their combinations with potash, soda, and ammonia, act energetically on carbonate of lime and on the oxides of iron, and play a highly important part in the disintegration of various kinds of rocks. (5.) The burrowing of earth-worms and other earth-dwelling creatures brings fresh particles to the surface, and admits the passage of air and water to the subsoil.

According to Darwin the solid rocks disintegrate even in countries where it seldom rains and where there is no frost. And in conformity with the views lately advanced by De Konnick, such disintegrations may be attributed to the carbonic and nitric acids, together with the nitrates of ammonia, which are dissolved in the dew.

Rocks of various hardness weather at different rates. Many of the slates and shales disintegrate rapidly. So do granite and gneiss. Purely calcareous rocks, however, weather quickest, the lime being dissolved out of them by the rain-water. Over some limestone rocks this gives rise to a lime-"pan" in the subsoil. The dissolved lime is carried down and often forms, with other materials present, a layer as of concrete, the lime acting as a cement. The same power which dissolves the carbonate of lime in solid rocks, dissolves also that which may be diffused through the soil. In chalk countries the rapidity with which the lime wastes is shown by the residuum of flints left on the surface; because though even these flints gradually disintegrate, they do not decay so fast as the chalk. In spite of much stone-picking, these flints continue to make their appearance.

The rocks which weather with most ease and rapidity do not always exhibit most soil: often the reverse. A pure limestone would exhibit hardly any weathered band or soil, because the carbonic acid of the rain would almost at once dissolve and remove the particles it acts upon. Even in the case of igneous rocks, the composition may be such that those which weather most rapidly may not show the greatest depth of weathered band upon the surface, owing to the removal of the particles as soon as disintegrated.

Denudation.—The same weather action which forms soil is also wasting or carrying them away. Soil is always travelling towards the sea. It is deepest in the valley and thinnest on the brow of the hill. The land movement consists for the most part of the mere sweeping downwards of its component particles by rain or thawing snow, or by surface drainage. The continued rainfall not only dissolves out of the soil a great deal of the soluble matter, but must eventually remove much of the soil itself. Indeed, our brooks and rivers, after heavy long-continued rain, show us by the yellow muddy color of their waters that they are carrying a vast quantity of sediment to the sea. All this sediment has come from the most easily washed off parts of the surface soil, upon which the rains have persistently been falling. It is, however, the fact that the soil, notwithstanding, remains nearly constant in quantity. Though, therefore, it is continually washed away, it is augmented from other causes, just as much on an average as it is diminished by denudation; and this augmentation evidently can proceed from nothing but the constant and slow disintegration of the underlying rock. If there were not a concomitant decomposition of the subsoils, converting them into surface soils, the solid rock would everywhere appear naked at the surface, as is the case in mountainous districts where the wasting away of the soil is more rapid than the rate of decomposition of the underlying rocks. Even the tillage and plowing of arable lands plays into the hands of the robbing weather action, by enabling it to act more powerfully on the soil, and to waste it in a higher degree than it could have done had it been protected by natural vegetation or by the grass of pasture land.

Alluvium.—If no denudation took place, the soil of every locality would be simply the decayed upper surface of the rocks underneath it. But, in proportion to the slope of the ground and the quantity of rain, the soil is moved from higher to lower levels, so that in many cases a good soil comes to lie upon rocks, which of themselves would only produce a poor soil. During every fall of rain, transportation of soil goes on, and the thicker soils of the valley are partially formed in this way.

The running water bears along the transported matter and leaves it when the force of the current diminishes; the finer portion being carried further; the extremely comminuted material moving as long as the current moves at all. When a river reaches a level tract on which its motion is slow, and over part of which it can flow in flood, all the suspended material, consisting of fine sand and mud, is deposited and constitutes the *alluvium,* or new land formed by such deposits at the river mouth.

Marine alluvial soils have a similar origin. The rising tide sweeps away the fine material from every exposed bank or cliff, and becomes loaded with mud and extremely fine sand, which, as it stagnates at high water, it deposits in a thin layer on the surface of the flats. This layer, which varies in thickness, is thus coarser and thicker at the outer edge of the flats than near the shore.

From the same cause, the earlier deposit of the coarse sediment, the lower strata of the layer are arenaceous, while the upper surface is fine and slimy. Thus the flats continue to grow until they reach such a height that they can be overflowed only by the high spring tides; and they at length become gradually covered with the coarse grasses and sedges which grow in such places.

Drift or Boulder Clay.—In addition to river and marine action, it must be borne in mind, however, that the abrading agencies of an ancient glacial period have done a great deal towards commingling the detritus of the different geological formations, producing widespread "drift" soils of various composition. This detritus is far from being uniformly spread over the island. In some districts it is absent, while in others it forms a thick mantle obscuring all the hard rocks. No richer source of soil could possibly be mentioned, for our drift-beds have been all formed by the breaking up of rocks of different geological formations, and of various chemical constituents.

It is no doubt true that in regions where there is a thick cover of "drift" the soil has little or no relation to the solid rocks below the drift, but this "drift" is there really the surface "rock," in the agricultural sense of that word; so that there is no exception here to the rule that, soil is rotted subsoil and subsoil is rotting rock.

Vegetable Mould is continually forming wherever plants grow. It is the foundation, and often the entire source, of the organic portion of the soil. Where vegetation is scanty, or where the produce of the soil is removed by man or animals, it occurs sparingly. Deep beds of this mould are, however, met with in forests under trees, and on dry land generally, wherever vegetation is rank and neglected.

Peat, like vegetable mould, is produced by the slow decay of plants and their remains in the midst of water. The peat may arise simply from the accumulation of neglected vegetable matter in moist situations. Where successive generations of plants have grown and decayed upon a soil, the vegetable matter increases in such a proportion that the soil approaches to a peat in its nature; and if in a situation where it can receive water from a higher district, it soon becomes spongy, and unfitted for the growth of any but coarse aquatic plants.

Another mode in which peat is formed is by the gradual accumulation and decomposition of aquatic plants in shallow lakes and stagnant pools. This kind of peat is of a more loose and spongy quality. What has greatly contributed to its formation is the destruction of ancient forests, either by the operation of some natural cause, or by the hand of man. When water gets collected or choked up, as in a morass for instance, many plants contrive to grow in it, and by their decay form peat—especially the "bog moss," which, while it grows above, decays beneath.

CHAPTER II.

PHYSICAL PROPERTIES OF SOILS.

Texture—Absorbent Power—Temperature.

Soils differ greatly, not only in chemical constitution, but also in physical characteristics; and, in our estimate of them, we must be guided by their climatic and physical relations no less than by the results of chemical analysis. It is comparatively easy to adapt the plant or crop to the nature of the soil when once we know what mineral ingredients are required by the one and afforded by the other; but it demands close observation and a more diligent application of means to bring the physical or mechanical qualities of the soil into the state most conducive to the growth of its natural products. The necessary influence of mechanical operations here becomes obvious, for the circumstances of air, moisture, and warmth, which are essential to the development of the changes which occur in the process of germination, are but slightly influenced by the chemical properties of the soil, being all dependent upon its mechanical condition. And this influence is not confined to the first stage of vegetation, for at no period of growth or maturity can the plants avail themselves of their full amount of food unless the state of the soil admits of the free passage of air and water, and favors the extension of the roots in all directions.

Texture of Soils.—In this respect the soil may vary from coarse pebbles or loose sand to the finest and most tenaceous clay. In general, however, those soils are best adapted for agriculture which consist of mixtures of sand with a moderate quantity of clay, and a little vegetable matter. When sand or other coarse material predominates, the soil is light and easy to till, and will grow all the crops suitable to the district; but it is deficient in the power of retaining water and the soluble and volatile parts of manure. When clay is in excess, the soil is heavy to till, and will probably grow fewer crops; it is too retentive of water, is not easily warmed, does not admit of access of air, and consequently does not facilitate those chemical changes in the soil and manure placed in it, which are necessary to prepare proper food for plants.

Clay lands, whether in the dry or wet state, are the most difficult to work; sandy soils and those containing much organic matter being the most easy. When land is worked in a wet state, we have not only to overcome the cohesiveness of the particles among themselves, but at the same time their attachment or adhesion also to the agricultural implements employed. In a wet climate, therefore, the working days for tillage will be fewer than in a dry one, and proportionately more so on clay soils than on light soils. Less work can also be done in a day with the same power on clay and heavy soils than on sandy or light ones. On clay lands, a pair of horses can seldom do the tillage of sixty acres per annum; but on light soils a pair of horses may overtake the work of eighty acres and upwards, except under very laborious rotations of cropping.

The terms light and heavy, as commonly applied to soils, do not refer to their actual weight, but to their tenacity, and the degrée of resistance they will offer to the plow or other implements. Sandy soils are, in the farmer's sense of the word, the lightest of all soils, because they are easiest to work, while in actual weight they are the heaviest soils known. Clay, also, which we call a heavy soil, because stiff and unyielding to the plow, is comparatively a light soil in actual weight. Peat soils are light in both senses of the word, having little actual weight, and being loose or porous.

Absorbent and Retentive Powers of Soils.—If there were no other difference in soils than that of texture, that which contained the greatest amount of finely divided matter would possess an advantage over the soils with coarser parts. One cause of this superiority consists in the greater absorptive and retentive power which finely divided matter possesses, due mainly, in all probability, to the immensely greater quantity of internal superfices in a given bulk or weight of the more finely divided soil. The ammonia floating in the atmosphere is continually being washed into soils, in solution with rain-water. Clay, oxide of iron, and the organic matter contained in the soils, perform the important function of absorption. This property of clay may be one of the circumstances which render clay soils better for wheat than sandy soils. But, although clay contains a larger porportion of this absorbed substance than sands or loams, it cannot be doubted that these must receive from rains the same amount of fertilizing matter as the clay; only they have less ability for retaining it, or at least for storing it up.

The soil, however, is not a mere sieve through which any matter in solution can pass freely. It has a power of retaining, as in a filter, many saline and other substances that may be present in the water permeating it. The experiments of Way, Vœlcker, and others have shown that when surface waters charged with the products of vegetable decay are brought into contact with argillaceous sediment, they part to some extent with their potash, ammonia, silica, phosphoric acid, and organic matter, which remain in combination with the soil; while, under ordinary conditions at least, neither nitrates, soda, lime, magnesia, sulphuric acid, nor chlorine are retained. The phosphates are probably retained in combination with alumina or peroxide of iron, and the silica and organic matters also enter into more or less insoluble combinations. It follows from these reactions that drainage-waters, especially from clay soils in a good state of pulverization, are found to carry off nitrates, sulphates, chlorides, or carbonates of soda, lime, and magnesia. In light and sandy soils the power of retaining nutritive substances is less than in the case of heavier soils, or than soils having much vegetable matter. Were it not for this power, the soluble substances present in the soil, whether naturally or applied in manures, would often be speedily washed out of it; and tillage and draining would much more rapidly impoverish the land than they do, by allowing its soluble constituents to be carried off by water.

The power of soils to absorb and retain moisture is in direct ratio not only to the quantity of organic matter in the soil, but also to the fineness of the particles of the soil. Hence it becomes important, in a practical point of view, to secure a proper degree of fineness in the particles of a soil if it is to withstand drouth. During dry weather plants require a soil which is both absorptive and retentive; and that soil which is capable of seizing atmospheric moisture, and holding it when the atmosphere is heated, is one of the best constituted soils. But "stiff clays, which take up the greatest quantity of water, when it is poured upon them in a fluid form, are not the soils which absorb most moisture from the atmosphere in dry weather; they cake and present only a small surface to the air, and the vegetation on them is generally burnt up almost as readily as on sands. The soils that are most efficient in supplying the plant with water by atmospheric absorption, are those in which there is a due mixture of sand, finely divided clay, and carbonate of lime, with some animal or vegetable matter, and which are so loose and light as to be freely permeable to the atmosphere. With respect to this quality, carbonate of lime and vegetable matter are of great use in soils; they give absorbent power to the soil without likewise giving it tenacity; sand, which also destroys tenacity, on the contrary, gives it little absorbent power." In accordance, then, with these observations, we find that the materials which are most influential in soils may be arranged in the following order, when their relations to moisture are considered:—organic matter, marls, clays, loams, and sands.

The Temperature of a soil depends very much upon its humidity. Dry land absorbs heat more quickly and loses it more slowly than that which is wet, and thus the summer temperature of our undrained districts will be lower than if they had been drained.

The temperature of drained land is in summer occasionally three degrees Fah. above that of undrained land. The greatest difference between the temperature of the soil and the air occurs in spring, the soil acquiring the proper temperature for the coming vegetation rather slowly, in consequence of the evaporation required in order to dry it sufficiently. In the autumn, it seems to have acquired a stock of heat which is sufficient for some time without exhaustion, while at the same time it operates favorably in sustaining the proper temperature for the ripening of later fruits and other crops. The surface heat is often preserved, too, in the autumn by rain; and in the spring rains aid in warming the soil. Emmon mentions an instance of rain whose temperature was fifty-four degrees falling when the earth was fourty-nine degrees, and the surface was raised soon after to fifty-one degrees. Dark-colored soils absorb heat more rapidly than light-colored ones.

CHAPTER III.

COMPOSITION AND FERTILITY OF THE SOIL.

Organic and Inorganic Constituents—Classification—Composition and Texture—Barrenness—Fertility, natural and acquired—Exhaustion and Restoration of Fertility.

Soil consists of an organic and an inorganic or mineral part; and we have seen that the former is derived from the roots and stems of decayed plants and from the manure and remains of animals, and the latter from the waste of the rocks forming the earth's crust.

Organic matter is most deficient in sandy soils and poor clays. Even in fertile soils, however, it often occurs but sparingly. In one sample of fertile mould, the amount of organic matter was ascertained to be only 1.76 per cent.; in the famous black soil of Russia it varies from five to twelve per cent. In leaf-mould the amount is much greater, and in peat the carbon alone sometimes exceeds sixty per cent. The carbon in the soil tends gradually to oxidize and to disappear, except where water accumulates and the climate is cool; so that if we exclude living roots and root fibres, there is, even in the oldest pasture-land, no great quantity of organic matter, notwithstanding the continued decay of the roots and underground stems of plants and the occasional addition of manure.

The Inorganic or Mineral portion of the soil consists of the same substances as the inorganic part of plants, with the addition of alumina. The mineral constituents of soils include the following substances:—

Silica.	Potash.
Alumina.	Soda.
Calcic carbonate.	Ferric oxide.
Phosphoric acid.	Magnesia.
Sulphuric acid.	Chlorine.

These constituents exist in very different proportions in different soils. The first three—sand, clay, lime—represent more than ninety per cent. of the substance of most soils; and, as one or other of them prevails, the soil is characterized as calcareous, clayey, or sandy. The most active constituents of the soil, however, phosphoric acid and the alkalies, occur in very small quantities, as do the other and less important constituents—magnesia, chlorine, and sulphuric acid.

Silica exists in very different proportions in different soils, but chiefly in an insoluble form, and that most largely in the poorest sands, fertile soils alone containing it in a soluble form. Sandy soils contain eighty per cent. and upwards of silica: even stiff clay soils from sixty to seventy per cent., and calcareous or lime soils and marls from twenty to thirty per cent. In sandy soil there is an abundance of silica, but it is not available. In clay it is also abundant, but it is the quantity of it which is soluble that determines its value as contributing to the food or life of the plant.

It is in the form of soluble silicates that silica does its work as plant food. Its use in the form of sand consists in its influence on the texture of the sand.

Alumina is a valuable constituent of soils as giving substance and stiffness of texture to the soil. In combination with silica (as the silicate of alumina) it is clay. It is contained in greatest proportion in the stiffer clays, but it rarely exceeds ten per cent. of the whole mineral constituents of a soil. Clay soils contain on an average from six to ten per cent. of alumina. In sandy soils it varies from one to four per cent.; and in marls, calcareous soils, and vegetable moulds from one to six per cent.

The larger the percentage of alumina in the soil, the more difficult is its cultivation—the adhesive character of the earth offering a stubborn resistance to the passage of the plow and other implements through it.

Calcic carbonate, a combination of lime and carbonic acid, varies from about ninety per cent. in some marls and limestone soils to mere traces in some other soils. Clays and loams generally contain one to three per cent. of this substance. Less than one per cent. may be regarded as a defective proportion. Where a soil is deficient in lime, the lime present exists in it mostly in combination with the organic acids, and is more abundant in the surface than in the subsoil.

Phosphoric acid is contained in all good soils, but only in small quantities, when compared with their other constituents. It exists in combination with lime, iron, and alumina. Phosphate of lime is its most common combination. It is generally found in very minute quantities, but in clays its percentage is sometimes more than one per cent. In general, even very fertile land contains less than this proportion, and the average amount is probably about a half per cent. The supply of phosphates is shown by analysis to be derived in the main from the rocks themselves. The fossiliferous rocks yield it most abundantly.

Potash, an element of felspar, is present in large quantity in soils derived from the primitive and igneous rocks. It varies in different soils from the merest trace to one or two per cent. Sandy and peaty soils and marls are in general deficient in this alkali. Soils rich in alumina are, with some exceptions, generally rich in potash. It exists in the soil in combination with silica, forming a substance which is to some extent soluble in water. Soda is a less important constituent in soil than potash, and, unless near the coast, is present in even smaller quantity.

Of the other ingredients which have been named, ferric oxide, invariably found in soils, is sometimes found in the subsoil in injurious forms. The ferric or per-oxide, better known as the red rust of iron, is its most favorable condition in the soil. In its less perfectly oxidized form, soluble in vegetable acids, it exists in undrained vegetable soils, and, on drainage, entering the pipes with the water which is being drawn off, it forms, on per-oxidation in the presence of the air, an insoluble ferric deposit, which is sometimes in quantity sufficient to choke the pipes. Magnesia is found in all fertile soils, in proportions, however, often amounting to a mere trace. Sulphuric acid and chlorine occur very sparingly in most soils.

Classifications of Soils.—In talking of soils, a precise nomenclature should be adhered to in preference to local terms. Otherwise men in different districts will often fail to understand what particular kind of soil is alluded to. The most common classification of soils is based on their composition; and the names applied to them take after their predominant ingredients. Thus where sand, clay, lime, or organic matter predominates in a soil, it is sandy, clayey, calcareous, or vegetable, as the case may be. A mixture of sand and clay is called loam. If it is needful to be more specific, loams, etc., are designated by the predominance in them either of sand, clay, or lime, as sand loams, or clay loams, etc. Soils are also popularly designated from their texture as light or heavy, porous or impervious; from their relations to heat and moisture as wet or dry, cold or warm; and from their measure of fertility as rich or poor, fertile or infertile, etc. Again, the class of crops respectively best adapted to each, has led to clays being spoken of as wheat and bean soils, and friable soils as barley and turnip land.

The Composition of the Soil is one of the conditions on which the fertility of a soil depends.

On this composition depends its supply of plant food. Fertility does not altogether depend on the quantity of organic matter present in the soil. There are some alluvial soils nearly destitute of organic matter, and yet of almost inexhaustible fertility; and there are peaty soils which are rich in organic matter, yet very barren. The organic matter of the soil, however, is of great value. It is constantly yielding by its decay matters which nourish the organic parts of the plant, and it is setting free, little by little, the earthy matters of its own ashes. It is also, by its decay, inducing chemical changes which tend to set free other matters held in combination in the particles of the soil. It renders clay soil more friable, and sandy soils more retentive of substances in solution; and these are certainly great uses.

The mineral matter of the soil is of equal importance. All naturally fertile soils contain a notable quantity of each of the different mineral substances which have been named, which are indeed essential to fertility, for a soil destitute of any one of them is more or less barren: fertility being limited by the minimum of any one necessary ingredient, even though the maximum of the others be present.

However fertile a soil may be, not more perhaps than one per cent. of its substance is, at any moment, in a fit condition for nourishing our crops. The great bulk of it is unavailable to the plant at any one time, and is only slowly liberated by the action of air, of moisture, of heat, and of manure. It is on the rate at which this liberation of plant food takes place that the natural fertility of the soil may be said, in a great measure, to depend.

A soil may contain abundance of phosphoric acid, potash, magnesia, etc., and yet be infertile, if these exist in the soil only as apatite, felspar, and serpentine, because these minerals do not yield their elements to the solvent agencies of the soil or plant rapidly enough to furnish the required amount of plant food. Nitrates and ammonia salts, which are the natural sources of nitrogen to crops, never need be present in the soil in more than the minutest proportion. It is only requisite that they be gathered or generated there as rapidly as crops require them. The process of nitrification, whereby inert or unassimilable nitrogen existing in the soil is converted into nitric acid, thus becomes of the utmost agricultural importance.

On the other hand, the nutritive substances which are yielded naturally by the soil may be in a state so soluble as to be very liable to waste before they can be taken up by the roots of the growing plants.

Everyday experience proves that soils differ greatly in these respects. Nearly all the materials which go to make up the structure of the earth's crust are such as to afford, by their decomposition, a soil fit for the support of vegetable life; but all rock-formations do not furnish equal amounts of these materials; and, while all soils have considerable power of retaining in their pores even the most soluble substances, some part with them too readily, and others retain them too firmly, or only part with them when exposed to various preparatory processes.

These differences are the result of geological formation, as well as of chemical composition.

A proper mechanical texture in soils is also essential to fertility. On the texture of a soil depends, not only its suitableness for the growth of different crops, but likewise the rapidity of their growth. It is this also which regulates, to a great extent, the soil's power of absorbing and retaining heat, moisture, and manure. To be fertile, the soil must be firm enough to afford a proper degree of support to the plants which grow in it, and yet loose enough to allow the delicate fibres of the rootlets to extend themselves in all directions. It must be of such a texture as to allow the free access of air, without which plants cannot live; and it must be close enough to retain, for a considerable time, the water which falls on it, and at the same time, porous enough to allow the excess to drain away. In this respect, the nature of the subsoil and the depth of the surface soil are both of them important. When a soil rests immediately upon a bed of rock or gravel, it will be naturally drier than where the subsoil is of clay and marl. On the other hand, a clay subsoil may be of material advantage to a sandy soil, by enabling it to retain moisture longer in dry weather.

For the fertility of a soil depends not only on its composition—not only its wealth as a full storehouse of what the growing plant needs as food, but on its efficiency as a laboratory in which the materials thus required are prepared for use. And it is in its relations to the water which is the great carrier to and fro of the ingredients which are at once the chemicals in this laboratory and the food in this storehouse that the efficiency of a soil in both these characters, and therefore its fertility, very materially depends. Unless there be a sufficiently free passage for the rain-water throughout the substance of the soil, neither will the food of plants be properly prepared, nor the stationary roots of plants be fed. It is in the great change thus introduced into water-logged soils by land drainage that its extraordinary power as a fertilizing agency depends, to which reference is made in another chapter.

The relative fertility of a soil is further dependent on the climate wherein it lies. Disregard of local conditions as to rainfall, temperature, aspect, height above the sea, and other necessary circumstances, may lead to very erroneous estimates of the value of soils. They may be the same in composition and texture, and yet differ greatly in value. Nothing is more certain than that the amount of rain, and the season of its descent, determine in a great degree the nature of the husbandry of the place, and the value of its soil for agriculture. The temperature of the air in any particular locality has an important bearing upon the actual productiveness of the soil, whatever may be its composition and texture, and however propitiously the rain may fall upon it. Other things being equal, we should expect that sheltered situations, with a good southern aspect, would be those in which we should find the capability of any given soil best exhibited. But though soil and rain and duly-tempered warmth favor us, these and many other considerations besides, may fail to determine, in every case, whether this or that plant may be grown within particular limits. That also depends on the presence or absence of its proper food, and it is here that art is available for meeting the defects of nature.

Causes of Barrenness.—They are of course the converse of those of fertility. The soil may be empty, considered as a storehouse of plant food, or locked up in stagnant water, and thus incapable as a laboratory in which that food is prepared. There are, however, special causes of infertility. This may arise from the soil containing something injurious to vegetation; such as an excess of organic acids, or the presence of small quantities of sulphate of iron or other poisonous ingredients. It may also be due to an excess of otherwise valuable ingredients, such as organic matter, sand, lime, or even clay. In the strict meaning of the word no soil, unless it contains some substance poisonous to plants, is absolutely barren; but one may call a soil barren which will not produce such plants as the farmer cultivates. Such a soil may be made fertile by adding to it the substances in which it is deficient; but if this cannot be done except at a cost as great or greater than that for which fertile soil can be procured, the soil may be regarded as practically worthless.

Natural and acquired Fertility.—The distinction here must not be forgotten. Sir James B. Lawes in discussing this subject, writes thus: "The natural fertility of a soil, whether high or low in degree, is, comparatively speaking, a permanent quality; it can only be injuriously affected by the continuance of an exhaustive system of cropping for a long period of time; it is the property of the landlord; and, excepting in the case of very light soils, it is the chief element in determining the rent-nature of the land. Acquired fertility, or 'condition,' as it is termed, is a quality distinct from the natural fertility of soil; it is due to the accumulation within the soil of manure matters which may be withdrawn or reduced by cropping within a comparatively short period of time. It is a quality dependent on the capital expended by the tenant in the purchase of cattle food or manures, and is, therefore, his property." But, as the proverb has it, "Nature passes Nurture;" and a soil which is naturally fertile is better than one which is fertile only by the help of manure.

"The fertility of a soil may be expressed," according to Caird, "by examples taken, first, in the natural state of pasture, and secondly, in similar soils after treatment. The maximum of fertility in the natural state is a rich pasture capable of fattening an ox and two sheep on an acre. Such soils are exceptional, though in most counties they are to be met with . . . . The minimum of fertility may be exemplified by a bleak mountain pasture, where ten acres will barely maintain a small sheep.

The artificial maximum or minimum which results from the treatment of soils of the same quality is more instructive, and may be clearly exemplified by taking two of the experiments which have been carried on by Mr. Lawes of Rothamsted for the last thirty years. Confining the comparison to the average of the last twelve years, the following was the weight in pounds of an average crop :—

	Corn. *lbs.*	*Straw.* *lbs.*	*Total.* *lbs.*
Wheat, grown continuously, without manure......	730	1,120	1,850
" " " with special manure..	2,340	4,928	7,268

The soils here are exactly similar and in the same field, strong land on clay with a substratum of chalk. The management is the same, in so far as culture is concerned; both crops are kept equally clean and free from weeds; the same seed is used, and they are exposed to the same changes of weather. The only difference is, that in the one case nature has for thirty years been unassisted by manure, and in the other the soil receives every year the various kinds of manure which have been found most suitable to the crop. The result of this treatment is a return of three times the weight of corn and four times the weight of straw, for an expenditure of manure which leaves a profit of one hundred per cent. on its cost. In both cases the wheat is grown continuously year after year.

Exhaustion of Fertility.—The effect of continued cropping, without manuring, is to reduce the stock of available fertility in the soil. But since it is the minimum of any one essential ingredient and not the maximum of the others which is the measure of fertility, it follows that a soil which is exhausted for one plant may still contain an abundant food supply for a plant of another kind. A rotation of crops will in such case defer the period of exhaustion. But whatever the crops cultivated, it is plain that continued cropping without the use of manures must ultimately bring us to a time when the crops grown will no longer pay the cost of cultivation.

The particular substance on which the crops grown have made the largest demands, and which was originally most deficient in the soil, will be the first to become exhausted. Further, the more available substances will be removed while the less soluble will remain behind; a poor soil will be reduced to sterility sooner than a rich one; a shallow soil will fail sooner than a deep one; and a light soil sooner than a stiff one. All soils, however, are capable of yielding annually from their stores of natural fertility a certain amount of produce, and this constant abstraction of their substance is not necessarily inconsistent with the maintenance of fertility; for, independently of the small quantity of vegetable food, so to speak, available for use at any one time, an immense store resides in most soils in a dormant condition, capable of gradual development as it is required.

Restoration of Fertility.—As cropping removes these substances from the soil, they are replaced more or less rapidly and completely by the agencies of the weather. The action of earth-worms is also useful in this respect, for it is as soil-fertilizers rather than as soil-formers that earth-worms are of importance to agriculture. Indeed, they are rarely met with in soils that are very destitute of organic matter. The richer the soil, however, and the more it is manured, the more numerous they are. Their action as soil-fertilizers consists in swallowing earth, leaves, and organic matter of all kinds, triturating it, converting it, and then ejecting it over the surface of the field. In this way they very soon effect a complete inversion of the soil down to a certain depth, especially on meadow land, which is left undisturbed to their operation. They even make additions to the soil by bringing up fresh matter from the subsoil. Every time a worm is driven by dry weather or any other cause to descend deep, it brings to the surface, when it empties the contents of its body, a few particles of fresh earth. At the same time it fertilizes the subsoil, by opening up passages which encourage the roots of plants to penetrate deeper, these passages being lined with excreted matter which provides a store of nourishment for the roots. On meadow land, Darwin found these worm-casts amount annually to eighteen tons per acre, and on good arable land to about ten tons. Dr. Gilbert has analysed worm-casts, and found them to contain .34 per cent. of nitrogen, which is several times more than is found in ordinary soils. Ten tons of these castings will thus yield eighty pounds of nitrogen, or as much as is contained in two acres of a wheat crop.

By various artificial means, tillage, drainage, clay-burning, the application of lime, or manures, the processes of natural soil-renovation may be greatly accelerated. And these are the subjects of the remaining chapters of this book. But it is plain from the natural influences, as well as the artificial operations, to which soils are amenable, that there is hope for almost any soil—that in few cases can land be so run out as to require the direct supply of all the substances which are needed to create fertility, for many of them are already present, and it only requires a little skillful management to exhibit them. It is on this principle that we must explain the practice, often to be seen, of allowing wornout land to rest for a while after a long period of mismanagement has exhausted its fertility. The success of this expedient, however, does not justify the practice, which is obviously most wasteful both of time and means. The amount of active fertility in the soil ought, by a judicious system of cropping and consumption on the farm, to be made nearly to reproduce itself year by year; and the gradual development of that which lies dormant, instead of acting as a sinking fund to wipe out the evils of past mismanagement would then go annually to increase the fertility of the land.

CHAPTER IV.

IMPROVEMENT OF SOILS.—DRAINAGE AND IRRIGATION.

Land-Drainage—objects, process, results, expense and profit.—Irrigation—object aimed at, methods adopted, results.—Sewage irrigation.

Land Drainage.—Whatever the composition or natural capability of a soil, its fertility depends materially upon its relations to the water which falls upon it. If the rain-water has free access throughout it, free passage through it, not only are ingredients added which the roots absorb for the nourishment of the plant, but these ingredients are available in the laboratory of the soil for those purposes by which plant food is manufactured from the material of soil itself and from the manure added to it; and, above all, the full use is obtained of a necessary carrier of plant food by the hungry mouths—the absorbent ends of root-fibres to which it must be brought. Upon the permeability, as well as on the composition of a soil, its fertility is thus very materially dependent; and land drainage, either natural or artificial, is essential to it.

When there is an excess of water in a soil, and no provision exists for withdrawing it, the interstitial canals become completely filled, to the exclusion of the necessary amount of air on which the activity of the soil, considered as a laboratory for the provision of plant food depends. When the soil is drained, the superfluous water flows off through the air canals, and only so much moisture is retained as can be absorbed by the minuter pores within the small particles of earth; and as there is, then, free communication through these canals between the pores and the drains, it is evident that the water will all be withdrawn from the soil except that which is held by capillary attraction. Thus the rain, which falls upon and is absorbed by the surface-ground, percolates towards the drainage level, flushing every crevice and canal in its descent, leaving behind it the nutritive ingredients which it carries in suspension or in solution, and on which the plants can feed as it passes by their roots, or which the soil, acting as a filter, extracts and appropriates.

The object of land-drainage is not merely to render wet ground sufficiently dry for tillage operations, but so to regulate the passage of moisture that, while the soil shall have every facility for absorbing the necessary quantity, stagnation, and the consequent starvation of the plants, shall be prevented. Almost all lands require it, in whole or in part, and there are few fields which can be economically cultivated without draining some portion of them.

The causes which wet the soil of any field requiring drainage must first be considered; when these are understood, it will be easy to decide upon the best means of providing a remedy. But in this consideration the strata of the district must be taken into account, as well as the contour of the surface, and the texture of the soil and subsoil of the particular field.

If the surface of the ground be level, and the structure of the soil uniform, the drains may be arranged at regular intervals apart, with the feeders at right angles to the mains, and the necessary slope must be gained by cutting upwards from a sufficiently deep outfall. In any case the mains must be placed at the lowest level, delivering into a ditch or brook, and the minor drains should run into them in the direction of the inclination of the ground. When the inclination of the surface varies, though there should be sufficient fall for discharge if the drains were cut throughout to a uniform depth, yet it is necessary to observe a sufficient uniformity of fall in the pipes to hinder any risk of a deposit of mud in any part of their course.

If the substrata consists of layers of various retentive power, their relative positions must be regarded in the arrangement of the drains. Instead of following rigid rules for fixing the proportionate depths and distances of drains in light and heavy soils, we must determine these points by reference to the thickness and order of the substrata no less than by the character or texture of the soil itself.

Practically these are determined by digging holes four feet deep here and there in a field and taking a drain of the intended depth up the field in their neighborhood. The holes will fill with water if the land needs draining; and the effect of the drain in emptying them at distances of three, five, seven yards, etc., will indicate twice that measure as the proper interval to be adopted between the drains.

If the upper bed be retentive, and of such depth that the drains cannot be cut completely through it, the best system to adopt will be that of comparatively shallow drains at close intervals; and, on the contrary, a pervious material should have deeper drains at wider intervals. If a thin bed of clay rests upon a porous substratum, the drains may be cut into the latter, or through it, according to its depth; and they must then be laid at frequent intervals. When the case occurs, as it sometimes does, that a free supersoil, about three feet in depth, overlies a comparatively thin bed of clay, it is often advisable to limit the depth of the drains to that of the porous bed. When springs, which are fed from a higher level, lie immediately below a clay substratum which exceeds the practicable depth of the drains, recourse may be had to tapping, by means of an auger-hole or vertical bore, which will open communication to the drains, by which the contents of the spring may be carried off, and the liability to mischief caused by their bursting forth at a lower level will be prevented.

The drainage of deep and wet boggy land is a gradual process, requiring sometimes years of patience before success is attained. Frequent open ditches should, at first, be cut as deep as the sides will stand, and then gradually deepened as the land subsides, taking care always to keep them well cleaned out. When the land has become sufficiently consolidated, the usual pipe drains may be put in, but they should be laid rather beyond the depth which would be thought necessary in a firmer soil of the same nature. If the moss will not carry the ordinary pipes, it will be advantageous to use collars with them, in order to prevent their displacement.

Marshes, and even lakes, which occupy a bowl-shaped cavity, rendering drainage by the ordinary means impracticable, have often been successfully drained by boring or digging through the impermeable surface layer where it is not thick, and rests upon a porous substratum of sufficient depth to receive the water and drain it from the surface. But this method must not be tried without due attention to the disposition of the sectional strata of the district, for the porous soil may be surcharged with water from a higher level, and the proposed cure might only prove an aggravation of the existing evil. In that case the object may be obtained by cutting a deep ditch or canal through the bank on a level with the bottom of the lake.

In ordinary practice it is the texture of the soil and subsoil, and the nature or the slope, which determine the proper depth and distance of drains. Deep drains are longer in beginning to flow, but, if the soil is porous, they will carry off the surface water, after heavy rains, sooner than shallow drains. They also drain a greater bulk of the soil, and allow the water time to deposit the particles of mould and manure which it carries down from the surface of the ground.

In an open soil, which the water penetrates freely, the drain will draw from long distances if the depth is great; but in stiff, compact soils, percolation is more difficult, and the drains will draw from a smaller distance than in free and open soils where the water finds a ready escape. No amount of depth will compensate for excessive distance on a compact soil, because the material either resists the passage of the water altogether, or the removal is so slow that the drainage is worthless.

The requirements of vegetation must also be considered in determining the proper depths of drains; and the depths to which the rootlets of the plants penetrate may afford some indication of how far the free subjacent water should be permitted below the surface. As its availability for their supply will be regulated by the porosity of the soil, the bottom of the drains may be at a less distance from the roots on a heavy soil than on a light one. In dry summers, grass-land, especially, is sometimes liable to injury, owing to the land being dried below the rootlets, which the capillary power of the soil is thus unable to feed.

Another circumstance which will occasionally have an influence in regulating the depth, is the degree of slope which can be obtained, according to the surface-levels of the district. Theoretically, water will flow if there is but the smallest possible deviation from a horizontal line, but in practice this is not sufficient, for it implies a perfectly smooth and regular bed, a condition which cannot be expected to exist in land-drains. The water should not pass too quickly through the soil, before it has time to deposit its nutritive ingredients, but neither should it be allowed to stagnate, as it will do if the drains are deeper than it can readily permeate, or if the fall is insufficient to induce a free discharge. When the drains are sufficiently active they will not allow the water to stand for any length of time on the surface after the most heavy rains.

For purposes of cultivation the drains should seldom, if ever, be laid at a less depth than three feet from the surface of the ground. In grass-lands two and one-half feet may be sufficient, but where other circumstances are favorable, three feet should be the minimum depth.

The laying of the pipes should be entrusted to a careful workman, who is paid days' wages, as more attention in the performance of the work is thus insured than when it is done by the drainer at piece-work.

It is very important that the pipes should be large enough for the quantity of water they have to discharge. If the fall is considerable, a pipe of less dimensions will suffice than where the inclination is smaller. In practice, after the depth and interval of the intended drainage have been determined by trial holes in the manner described, and after any particular springs of water have been dealt with by special conduits taken through the wet spots thus created, and after all old water channels have been furnished with pipes laid at sufficient depths, and proprly filled in—the systematic drainage of a field which needs the operation is begun at the lowest level in it. The ditch is cleaned out by which the water is to escape. The main drain is dug (from a point six to eight inches above the botton of the ditch) along the lower edge of the field parallel with its side, from which it may be distant five yards or more, and as deep (to at least four feet) as possible. Into this drain the minor drains deliver over the top of the four to six-inch pipes which are placed in it. These minor drains, at the depth which has been resolved upon, are taken right up the slope, unless it be very steep, and two-inch pipes are placed in them. If the field is more than two hundred yards long, there should be a second main drain crossing it midway of its length, into which the upper series of minor drains deliver. The pipes should be carefully placed and carefully covered with the earth taken out. It is not necessary to put straw or turf over them before the earth which has been taken out is replaced. If there is any considerable remainder of the earth, it should be spread on the land, all stones being removed; and the turf, which in pastures has been first dug out, should, as soon as the earth has settled sufficiently, be replaced and rolled down; and the work may then be considered complete. It will often be possible to economize the labor by sending a plow along the line of each drain to turn out the first six inches, by horse-power. A double furrow will be necessary to open up the work efficiently; and in the case of grass-lands the plowing will be more effective if it be not too deep. And then these furrow slices, thrown out on either side without being detached from the land, can be brought together over the finished drain and rolled down. But the operation cannot be considered complete without careful provision for its permanence by a properly built outfall. The last pipe of the main should pass through brickwork whose foundation is laid below the level of the bottom of the ditch, and it should be protected by a flap or· gird. And the exit-water should fall from this opening on to a slab of stone laid on the bottom of the ditch, so as to hinder any risk of undermining the brick-work by its continual fall.

The cost per acre of land-draining is more generally covered by the consequent increased value of the land, than that of any other agricultural improvement. Whatever the interval or depth, the expense depends on the character of the soil or subsoil, the local rate of wages, the cost of the tiles, and the distance of the kiln.

In all cases it will be understood that the end desired is the nearest possible approach to the natural examples of the best soil resting on pervious subsoils, where the rainfall finds a gradual passage through the soil and subsoil, sinking always where it falls, carrying the generally warmer temperature of the air into the land—carrying also many an element of plant food, which the air contains, directly to the roots of plants—carrying, too, the air itself, the great oxidizer, amidst the matters organic and inorganic which require its influence for their conversion into available plant food—proving, by its action as a solvent, and its passage over the immense inner superficies of the soil, an active caterer for the stationary roots. At the same time it is hindered from doing the mischief which on undrained land the rainfall cannot fail of doing. The manure particles of the soil, if they do to some extent escape through drainage, are at any rate not washed wholesale from the surface into the furrows and ditches, which in the case of undrained land receive them without the subsoil having had a chance of retaining them.

Irrigation.—This, which at first seems the exact converse of land drainage, is but another example of the fertilizing use of water when properly employed. In both cases it is the passage of water through the soil which is the object aimed at; in both the water is useful as a carrier of temperature and of various elements of plant food; in both the benefit is derived to some extent from the increased activity induced in those chemical processes within the soil by which plant food is derived from the comparatively inert condition in which it naturally lies. In both processes it is the stagnation of water upon or in the soil which is the evil to be removed; and there is rarely any good derived from irrigation unless it be accompanied by land drainage. Of course the conditions under which the process is conducted are very different in different climates, and in our temperate climate we can hardly realize the advantage of irrigation. In many tropical countries rain falls so seldom, and at such lengthened intervals, that field irrigation affords the only possible chance for the former to grow profitable crops. In our own country it is not as the necessary provision in the absence of which the land would be barren, but it is only as increasing the activity of the fertilizing agencies already present that irrigation acts.

Soils suited to Irrigation.—Light porous soils, and particularly gravels and sands, are most improved by irrigation. Tenaceous and clay soils are seldom benefited by it; never, except in connection with thorough draining. In all cases, indeed, the drainage of the land must precede its irrigation. The soil to be irrigated must be in a condition enabling it to drain itself dry; otherwise irrigation, so far from proving a benefit, may be productive of the worst results. It is not only important that water be brought into the ground; it is equally important that it should pass off immediately after accomplishing the object sought.

All waters are suitable for irrigation except those containing mineral substances deleterious to vegetable life—such as the drainage from peat swamps and mineral springs, etc. Water from a running stream or river is generally superior to that from wells or springs; the former not only containing many salts which it has dissolved out of the soil or rocks as it passed over them, but being also more richly freighted with bodies extracted partly from the air, such as oxygen and ammonia. Of spring and river waters, those denominated "hard" are the best, and owe this quality to the presence of sulphate and carbonate of lime and magnesia.

Effects of Irrigation.—The first effect of water, when made to flow over the soil, is to soften it and render it more permeable to the roots of plants, and to the air. Water acts still further in dissolving out the food, and producing those chemical changes which must take place in the manures before they are fitted for nourishment. And owing both to this and to its conveyance of fertile matters from a distance which are deposited on the fields overflown, the increase from irrigation is sometimes four-fold, when the soil, the season, and the water are all favorable; and it is seldom less than doubled. The quality of grass from irrigated meadows is but slightly inferior to that grown upon dry soils; and for pasturage it is found that animals do better in dry seasons upon the former, and in wet upon the latter.

Modes of Irrigating.—These must depend on the configuration of the surface, and the supply of water. Sometimes reservoirs are made for accumulating water from rain and inundations; but the usual source of supply is from streams or rivulets, or copious springs which discharge their water at a level above the ground to be irrigated. The former are dammed up, to turn the water aside into ditches or aqueducts, through which it is conducted to the fields, where it is divided into smaller rills, and finally spread over the surface, sinking into and through the soil. When it is desirable to bring more water upon meadows than is required for saturating the ground, and its escape to fields below is to be avoided, other ditches should be made at intervals upon the slope, to arrest and carry away the surface water.

Ridge-and-Furrow or Bed-Work System.—Where the land is nearly level throughout its surface, it is laid out in a series of ridges. Along the top of these the irrigating channels are led, from which the water flows over either side, being taken up by the furrows, which occupy the hollows between the ridges. From the main conductor, and at right angles to it, the various feeders are taken off. These consist of smaller trenches four or five inches in depth, made widest, say twelve or sixteen inches where they issue from the main conductor, and gradually lessening as they recede from it. They may be formed at distances of ten yards or less; being made nearer on stiff soils, and further apart where the soil is loose and porous. They occupy the ridge lines of the lands in which the field is laid, and the furrows in the hollows between these lands communicate with a main surface drain, at the lower part of the meadow. The drain conveys the water back to the river from which it was taken; or becomes in its turn the main conductor to another meadow on a lower level; and in this way several meadows may be irrigated by means of the same water. This is known as the Bed-Work or Ridge-and-Furrow system. It is only suitable to grass lands, and to land which has nearly a level surface.

The Catch-Work System.—On a sloping surface a different plan must be adopted for the conveyance and distribution of the water. The feeders are not carried longitudinally down the meadow, but across the line of descent. They are filled as before from a main conductor; but the water having overflowed the lower side of each, is not discharged into smaller drains, as in the former case, but into the next feeder lower down; the purpose of the catch-furrow being to cut off the rills into which a surface flow is apt to collect, and re-start the overflow evenly once more. The water is thus conveyed from feeder to feeder until it reaches the main drain, at the lower part of the field. This is termed the Catch-Work system, and as it can be adopted where the surface is too much inclined to admit of bed-work, it is frequently practicable where the other is not, and is often combined with it in the same meadow where there are inequalities of surface. On arable land the catch-work system is best, as the bed-work would be continually destroyed. It is also less expensive to begin with than laying the land out in beds on the ridge-and-furrow system.

Time for applying Water to Meadows.—Where the winters are not severe, water may be kept many days at a time on the fields during the entire season of frosts. This protects the grasses, which, on the approach of warm weather, at once start into growth and yield an early and abundant crop. But in general this system cannot be successfully practised. The water may be admitted, at proper intervals, freely during the spring and early part of the summer, when vegetation is either just coming, or is going forward rapidly. It is sufficient to flood the surface thoroughly, and then shut off the water for a time. The water should be taken off before the grasses commence ripening: indeed, the common use of the water meadow in localities where the soil abounds in lime where they are most useful, is in providing the earliest succulent food for ewes and lambs, which are folded on them long before the grass throws up a flower stem. When kept for hay, immediately after the grass is cut, the water may be let in as occasion requires, during the drouth of summer; and pastures may be irrigated from time to time as the weather may demand, throughout the entire season.

Quantity of Water Required for Irrigation.—As to the quantity of water, it necessarily varies with the nature and condition of the soil, with the character of the subsoil, with the inclination of the surface, and with the crops cultivated. In Italy, it is generally held that the continued discharge of one cubic foot per second during twenty-four hours, is sufficient for the irrigation of four acres of meadow land. Hence, as the total volume discharged in that time amounts to eighty-six thousand four hundred cubic feet, and the area watered to one hundred and seventy-four thousand two hundred and forty square feet, it appears that a stratum of water equal to nearly six inches in depth is in this case spread over the surface of the meadow. Twelve waterings are given during the season, at intervals of fourteen days. The above calculations assume, however, that the whole water is absorbed by the soil, which is never the case. The absorption in each watering in that case probably ranges from half to one-third of the total quantity of water employed.

In English water-meadows the amount of water poured over the land far exceeds this amount; and the best effect, when the water itself brings not only warmth but food, is obtained where there is a continually moving thin layer of water over the whole surface in addition to the quantity which passes through the substance of the land to the drains in the subsoil.

Sewage Irrigation, by which the greatest luxuriance of growth known to English agriculture is obtained, is conducted generally on the "Bed-work" system. The most rapidly growing succulent crops, and Italian Rye-grass is the best of them all, are employed, and the water is poured on probably at the rate of four hundred tons per acre, equal to a thickness of four inches of water, during a few hours twice in the growth of a single crop or cutting. The land being drained passes the whole of this rich and fertilizing flood among the fibrous roots of the plants by which its substance is permeated. And a cutting of ten to fifteen tons weight per acre of the grass is obtained as the result of not more than a month or five weeks' growth. The land is soaked twice or thrice at intervals of a fortnight after each cutting; and four or five cuttings of grass are thus obtained from the appliction of four or five thousand tons of the filthy water in the course of the year. Here, as well as in ordinary irrigation accompanied by land drainage, the result is due to an added temperature, and an addition of plant food, both of which the soil experiences, and especially to the constant motion and passage of this food beside and among the hungry roots of the plants which feed upon it.

CHAPTER V.

IMPROVEMENT OF SOILS.—MIXING, CLAYING, LIMING, CHALKING, MARLING, BURNING.

MIXING SOILS: Clay, Sand, and Lime.—CLAYING: Process, Cost.—LIMING: Marling, Chalking.—BURNING: Paring and Burning, Stifle burning, Clay burning.

Mixing Soils.—Soils which possess conspicuous defects in their physical and even in their chemical properties may in many cases be rendered fertile and productive by a proper admixture. Loams, indeed, which are perhaps the most productive kind of soils, are naturally produced in this way, being a mixture of sand and clay. The nearer, therefore, we can bring a soil of a different nature in approach to this character, the greater probably will be its improvement.

When a soil is too clayey, it will be improved by an application of sand or sandy loam; calcareous, sandy, and peaty soils are equally benefited by the addition of clay; while calcareous earth may be added to clays, sands, and peats with the certainty of ultimate and permanent benefit. There are thus at least four varieties of soil which may be profitably improved by admixture, if circumstances are favorable. There is this, however, to remark as limiting our ability in this respect—that it is only those earths whose presence in comparatively small proportion is sufficient that we can usefully apply. If land be too stiff, it would probably need its sandy part to be doubled in order to make the land as friable and loose in texture as is desired; and there might thus have to be an addition of five-hundred tons of sandy loam per acre—a labor whose cost is absolutely prohibitive. To double the percentage of alumina in a very sandy soil, and thus strengthen its texture and improve it for every kind of crop, need not involve the addition of more than fifty to one-hundred cubic yards of marl or clay—an operation which is quite within ordinary farm practice. In this connection also it is necessary to ascertain the nature, not only of the soil, but of the subsoil, the latter often affording the readiest means of improving the former. Where a vegetable or a sandy soil, for example, rests immediately upon a substratum of clay which is near the surface, the clay is often dug up and the surface top-dressed with it. Contrarywise, where the clay is uppermost some good may sometimes be done by deepening it and mixing it with the sandy layer below. Where the soil and subsoil are similar in character and cannot be used in that way, it may still happen that two soils of opposite properties occur sufficiently near to one another to be used for mutual improvement.

There are situations, however, where neither of these advantages will be found to offer; the field, the farm, or even the entire district may be uniformly sandy or clayey; and other alternatives than mixing must then be resorted to. The light soils will probably be consolidated by sheep-folding, and by heavy rolling; while the strong lands will be rendered more workable by having green crops plowed under and by being heavily dressed with caustic lime in addition to ordinary manurings.

The benefits of an admixture of soils are obviously two-fold, the mechanical texture as well as the chemical composition of soils being altered and improved. A poor sand, for instance, after an addition of clay or marl, is rendered richer as well as stronger and more substantial, so that plants thrive better in it, and a less quantity of manure will suffice to afford a full crop.

Claying, as we have seen, may be usefully followed as a practice to be adopted and repeated on sandy, peaty, and calcareous soils. The quantity necessary will depend on the quality of the clay used, and on the character of the soil to be improved. It will also, to some extent, be regulated by the facilities for obtaining it, and by the distance from which it is to be brought. If the clay has to be carted from beyond the field, the operation will be found laborious and expensive. It takes one-hundred and thirty-four cubic yards to cover an acre an inch deep; but this is a very heavy dose when we consider that the ordinary depth of cultivation does not exceed six or eight inches. The usual application varies from fifty to one-hundred cartloads per acre.

The clay is spread upon the field before winter, so that the frost may break it down and render it fit to be intimately mixed with the soil before working the land in the spring. There are various methods of conducting the operation. If the subsoil of the field supplies the material, it is usual to open a number of deep furrows, at twelve or twenty yards apart; and as the clay is dug out it is spread equally over the surface within range, so as to cover the whole interval. When the distance is greater, the plank and wheelbarrow will afford the readiest and most economical means of working up to the point where carts would have to be employed. In extensive operations of this nature, especially where the material to be applied is situated at the end of the field to be operated on, or beyond it, the work may be done by means of small trucks and a portable railway readily laid.

The cost of the process necessarily varies with the nature of the material, the quantity applied, and the distance to be carted, etc. A dressing of clay will cost more per cubic yard than a dressing of sand, when the latter is a desirable application, from the difficulty with which in the former case the manual portion of the labor is performed.

Liming is useful not only as adding a necessary element to soils deficient in it, not only as constituting a mellowing and ameliorating agency in respect of the texture of the soil, but also as supplying an important agency in vegetable soils, and especially in clay soils, in the general chemistry of the land on which the provision of plant food depends. In marling especially, as well as in liming proper, it is the calcareous element which is the most active of the elements supplied. In the latter, of course, it is the clay which gives the marl its characteristic texture, and renders it adapted especially for the lighter and more vegetable kind of soils. The claying, which has added so much to the fertility of the Fens of Cambridgeshire and Lincolnshire across the water in England, owes its fertilizing influence, to a considerable extent, to the lime which it contains.

Chalking.—This is a common practice on the edge of chalk districts on clay soils, and wherever lime is deficient in the soil, is found beneficial, both as improving the texture and as adding plant food directly to the land. Some of its fertilizing influence is no doubt due to the small quantity of phosphoric acid which it sometimes contains; and its influence on the soil and its contents is of the same kind as that of caustic lime, though less energetic.

The chalk is carried on to the field perhaps eighty to hundred cubic yards per acre, set down from the carts in little heaps four or five yards apart, thereafter spread and left to the influences of a winter frost, which disintegrates the mass and enables its more perfect mixture with the soil.

Paring and Burning.—This was at one time a common method of breaking up old sward in some countries of the old world, but, except in a few districts, the practice has fallen into disuse. There is, however, no quicker or better way of bringing an old turf into tilth. It saves time, and always ensures a crop, and a good one. This is easily accounted for. It liberates plant food from the minerals of the soil; it purifies, sweetens, and cleanses the soil, breaking up and driving out injurious acids, destroying grubs and parasites of various kinds which prey upon both crops and cattle, and killing the seeds and roots of weeds; and it improves the mechanical texture of clay soils. The loss of nitrogen which occurs through burning, will be amply made up by subsequent liberal management in all cases where the mechanical texture of the soil does not suffer; and injury would ultimately result only in the case of a few sandy soils.

The surface of the land is taken off to a depth of two or three inches by the paring plow, or with the breast-plow —a paring tool on a long shaft with broad horizontal T-handles shoved horizontally by thrusts from the thighs, which are protected by wooden shields strapped to them. When the weather is dry, the turf will be ready to burn in a fortnight. A little straw or wood is taken to begin with. Then drier bits of turf are put on the fire. As the heap burns, more turf is carefully put round against the openings whence the smoke issues. This goes on, the heap continually growing in size, and the burning going on inside, though there never appears any blaze. After the first fires are well lighted, they serve to light all the other heaps, and no more straw is wanted. When all the heaps are lighted, the workman goes from heap to heap adding turf until the whole is burnt or charred.

A good deal has lately been taught us about the conservative influence of the living plant, whether crop or weed, on the fertilizing contents of the soil. Nevertheless, as a bit of good practical farming, we venture to recommend the practice of paring and burning stubbles in the autumn. If set about as soon as the corn is cleared off the fields, no employment of men and horses at that time will pay better. The land gets an effectual cleaning, such as will be a check on weeds throughout the entire rotation. Plant food is at the same time set free. The soil is, moreover, brought at once to a fine tilth ; and, if sown immediately, the land may be covered with a vigorous growing and useful catch-crop in less time than would have sufficed to clean it without burning. The crop is usually consumed on the land ; but, if organic matter is required in the soil, it may be plowed in as green manure. In either case the land will be covered during winter, and loss by drainage prevented ; it will be directly enriched by sheep-folding or green-manuring, and it will be in the most favorable condition, both as regards cleanness and tilth, in the spring.

The work is commenced by broad-sharing the stubbles twice over in opposite directions, to a depth of about three inches. This is harrowed. Then, when all is dry, horse and hand rakes bring the loose soil and weeds into heaps for burning. Straw is only used, when necessary, to start the first fires with. When the heaps are half burned through, the clods are raked up towards the fire, and fresh earth put on the top. This is repeated the last thing at night. Next morning, if all has been properly managed, the bulk of the heaps will be sufficiently burned to have killed all vegetable and animal life that was contained in them. After this, the fire requires a little trimming and tucking up to complete the work. The heaps may be made to contain as much as forty bushels each ; and forty such heaps per acre, when spread and plowed in, often have an effect on the subsequent crop equal to a dressing of dung or guano. The burning, especially on calcareous clays, shows its good effects for several years, and the land is tilled at less cost by reason of its working more easily.

Clay-Burning.—Stiff clays are often surface-burned, in the manner described above, with the object of ameliorating their texture and rendering them more workable. The fertility of the soil is greatly increased at the same time, especially in the case of calcareous clays.

Cobbett recommends not to burn the land which is to be cultivated, but other earth for the purpose of getting ashes to be brought on the land; and he advocates burning within walls of turf or earth, instead of in heaps above-ground. As he points out, the principle of clay-burning is slow combustion, and this you are sure to effect if you can check it by addition to the heap. When the heap is fairly alight, put on more clay wherever the smoke appears, but not too much at a time. This is continued until the heap is large enough, when the fire is allowed to extinguish itself.

CHAPTER VI.

SUB-SOILING, TRENCH PLOWING, TILLAGE OPERATIONS.

SUBSOIL PLOWING: Deepening and Stirring.—TRENCH PLOWING.—TILLAGE OPERATIONS: Plowing, Cultivating, Rolling, Steam-plowing.—Depth of Tillage.—Stubble Cleaning.

These operations tend to loosen the hard earth below the reach of the ordinary plow, and to facilitate the escape of water from the surface; they promote the circulation of air, and afford a more extended range for the roots of the plants, by which they obtain additional nourishment; and they secure the crops against drouth, by enabling them to penetrate into the region of perpetual moisture.

Subsoil Plowing.—The ultimate object of this operation is, of course, the deepening of the soil and loosening the subsoil. This invariably follows from opening the subsoil to the ameliorating influence of the elements; and the beneficial result is due to the accumulation of vegetable matter below the ordinary range of the soil by the roots penetrating deeper and being left to decay in the bed where they have grown. The subsoil plow merely stirs and opens the subsoil: it does not turn a furrow. A common plow goes before, throwing out a large open furrow-slice of the active soil; the subsoil plow follows, entering to a depth of six or eight inches below the bottom of the surface furrow; and the next furrow of active soil is thrown over the last opened furrow of the sub-soiler.

The subsoil implement requires to be drawn by four or more horses, according to the nature of the soil and the depth of working.

Though of great benefit on land which is sufficiently dry, subsoiling does more harm than good on wet lands. It is, therefore, only to be employed as an auxiliary to draining, and not as a substitute for it. Some time must elapse, however, between draining and subsoiling. When properly done it increases nearly every good effect of underdraining. Especially does it diminish injury by drouth, by loosening the soil and admitting air to circulate among the particles of the subsoil and deposit its moisture. It deepens the soil, and renders available matters which are perhaps deficient in the surface soil. It also improves the drainage.

Trench or Deep Plowing.—This is advantageous to such lands as are of the same nature to a considerable depth. For those lower parts of the soil, which have become filled with manure which the rains have carried down below the surface, are thus thrown up, to contribute to the nourishment of crops. Deep plowing is also useful on thin lands where the upper layer is too clayey and compact, and rests upon a bed of sand or limestone. By plowing deep, the sand or lime is mixed with the clay above, rendering it more fertile than it could be made by any other means. There are, however, cases in which, from the defective composition of the subsoil, or other causes, it does more harm than good. Good effects can only be obtained from trench plowing when the chemical composition of the lower soil is such as to supply in increased quantity the essential constituents of plant growth.

Where the subsoil is inferior, the deepening of the soil must be made a gradual operation, and a very small quantity of the raw material brought to the surface at a time. The sub-soiler effects this object much better than the trench plow, as in the former case the subsoil is opened up and exposed to the weathering action of the atmosphere without bringing it abruptly to the surface.

ORDINARY TILLAGE OPERATIONS.

Whatever the physical or chemical properties of the soil may be, it will produce but little if not well tilled. And what is true in this respect of the best soil, applies in far stronger terms to the worst.

Apart from its immediate end, the provision of a proper seed-bed, the objects and effects of tillage may be enumerated thus :—

(1) To stir and loosen the entire soil to a sufficient depth : so that the roots of plants may freely extend themselves in search of food.

(2) To pulverize the soil and mix thoroughly its constituent parts, so as to increase its absorbent and retentive powers, and to effect an equal and economical distribution of manure.

(3) To destroy weeds and foreign plants, which rob the crop of food and check its growth.

Let us add that, by opening the soil, and rendering it permeable to air and water, the inert materials contained in it, both organic and inorganic, are convertible into soluble plant food. And in regard to many of the insects which prey upon our crops, especially such as work beneath the soil at the roots of plants, frequent tillage is found to disturb them and bring them to the surface where they get picked up by birds.

Tillage operations include all soil operations which apply directly to the cultivation of farm crops—plowing, cultivating, harrowing, and rolling, or whatever else is done to bring land to a proper state to receive the seed. They also include the operations of hoeing and weeding the ground after it is planted.

Plowing.—In plowing we break up the ground into furrow slices, turning them over in such a manner that a new surface is presented to the atmosphere. This or some other mode of loosening and turning up the under parts of soils is necessary to fit them for the reception of the seed and the growth of crops.

The object of plowing being to expose the upturned soil to the atmosphere and to create the greatest quantity of mould the furrow-slices can produce, it follows that the furrow-slice which shows the greatest surface will answer these ends most effectually. In the case of a square cut furrow-slice this is found to result when it is laid at an angle of forty-five degrees; and to this end its width must be to its depth as about ten to seven. If the furrow-slices are ragged, open, and broken, and if, being cut of various depths and widths, they are laid at different heights, the work is inferior. A uniform depth of tilth cannot then be provided by the harrow, and the seed will be unequally buried.

On lea ground the furrow is usually eight to ten inches in breadth by five to seven in depth. The medium depth of good plowing is six or seven inches. Shallower plowing is often inevitable on thin soils, while on deep land the stubble furrow may be ten inches or more in depth.

The term "feering" is applied to the commencement or opening of a land or ridge; and the process varies according to the state of the land to be plowed. On lea ground, as also on stubble land, there is generally an old furrow to go by, in which case two shallow furrow-slices are then turned, the one against the other; and along each side of this commencement the plowing moves. On turnip land, or where there is no old furrow to turn the first furrow-slices into, two furrows are thrown out, and then turned lightly in as before. The plowing goes on in this direction, the horses always turning to the right-about at the end of the furrows until half of the land or ridge is plowed. The plowing so far has been what is technically called "gathering." At this stage, however, a second feering is commenced, and the same order followed until another half land has been gathered. Thus, if the distance between the two feerings was ten yards, five yards would be gathered in each case, and five yards of unplowed land still lie between them. In order to plow out this, the plowman now alters his course, and turns always to the left-about at both ends, laying furrow after furrow towards the inside of each feering, until the two plowed lands meet. This is known as "casting," "cleaving," or "splitting." On all but lea ground the open furrows ultimately left are usually turned in by running the plow once or twice back upon the last turned furrows. After this, the seed harrows take out all traces of the open furrows, and leave the land entirely level.

It is, in some districts, a common practice to move only one half the land at certain seasons by plowing each furrow-slice on to its own width of unmoved soil. This, which is called "raftering," is sometimes done in the case of foul land to enable the harrow to deal perfectly with one half of the soil at a time. It is also a common practice to rib clay land before winter by plowing two furrow-slices together over an intervening width of about twelve inches—thus creating a ridgelet thirty inches wide on which the frost can exert its disintegrating effect.

The points of merit in plowing are—(1) a straight furrow of uniform width and depth; (2) a clean cut slice, both on its land side and floor; (3) a well laid furrow-slice, having regard to compactness and form; (4) complete burial of the grass or stubble turned in; (5) a uniformly plowed ridge; (6) a finish showing an open furrow with a clean narrow bottom, the last furrow-slice being equal in width and height with the others.

Many calculations have been made to prove the waste of time consequent upon short furrows. Under average circumstances a pair of horses will plow an acre of grass land in a day of nine hours. On turnip land of the same quality rather more than an acre will be plowed in a day, and on stubble land one and one-quarter acre. A considerable difference will, of course, be found in the work accomplished by different horses and men, even on the same land. With a furrow nine inches wide, exactly eleven miles are travelled in plowing an acre. A quarter of the day or more is generally used in turning at the headland.

Cultivating or Stirring.—The cultivator merely stirs the soil and does not turn it over like the plow; but it can work to an equal depth. It is especially useful in a spring fallow after autumn plowing, as the winter-weathered tilth is thereby retained on the surface, and the moisture of the soil is less evaporated than when the land is spring plowed—a point of the first importance in turnip cultivation. It is also much used in preparing light land just cleared of roots for being sown with spring grain and seeds, as it furnishes a fine mould and keeps the manure near the surface. Fitted with broad points, and worked at a shallower depth, the cultivator is the most effective implement in use for stubble cleaning after harvest. The substitution, when possible, of the cultivator for the plow is attended with a considerable saving, both of time and labor.

Cultivators are adapted for either two or four horses, though the same implement which can be worked with ease by two horses on a light soil or at a shallow depth, will often require three or four horses on stiff land, or where deeper working has to be practised. If the nature of the soil and work admits of it, however, two horses in a light cultivator will do more than half the work of four yoked to a larger implement, as they step more freely and with greater ease to themselves. On light land, a two-horse cultivator should work five acres of fallow to a depth of about six inches, and four acres to a less depth on land where roots have been fed off; on stiff land, or working to a greater depth, a three or four-horse cultivator would do about six acres in a day.

Harrowing (1) pulverizes the soil to a depth of two or three inches, and reduces to fineness the surface clods and lumps that are left after plowing, cultivating, or digging; (2) it shakes out and separates the weeds that are in the soil; (3) it smooths surface inequalities, by which means the seed is more evenly deposited, and is more likely to have a uniform germination; and (4), after the seed is sown, the harrow buries it at a moderate depth beneath the surface. We might add a fifth use; for it is in many cases a good practice to harrow the winter-sown wheat in spring, and break up the weathered pan upon the surface.

The usual direction of harrowing after seed is sown is first along the furrows, then across, and finally along again. The quantity of land harrowed in a day depends in a measure on the kind of harrowing as well as on the kind of harrow used, and on the nature of the soil. A two-horse set of ordinary harrows covers, usually, a width of seven and a-half feet. That is equal to ten nine-inch furrows with the plow; so that if the teams travelled at the same pace, a pair of horses ought to harrow as much land in one day as they could plow in ten. But horses, as a rule, travel a good deal faster, and consequently farther when harrowing than when plowing. It follows, therefore, that if a plow, travelling at the rate of eleven miles a day, with a nine-inch furrow, turns over exactly one acre of land, a set of harrows, covering ten times the width of a nine-inch furrow, and travelling one-fourth to one-third faster than the plow, must get over twelve or thirteen acres a day: that is, when giving one turn of the harrow, or a single tine, as it is called. With a double turn, only half that quantity of land would be covered in a day. These are average quantities on average land.

Rolling (1) breaks those clods or lumps which have resisted the action of the harrow; (2) it presses down surface stones, etc., so as to be out of the way of the scythe or reaping machine; (3) it gives a greater degree of compactness to soil which is too light and friable, making it firmer around the roots of plants, and at the same time a less favorable breeding-ground for many kinds of insects; while the smoother surface presents fewer points of evaporation; (4) it presses down and makes firm the ground about newly-soon seeds; and sometimes (5), when very small seeds are to be sown, it is well to roll the ground first, so as to level it thoroughly and facilitate a more equal distribution of the seed than could otherwise take place; (6) it is used to press into the ground the roots of those plants sown in the preceding autumn which have been detached by frost.

A spring rolling on a field of winter grain will often, by firming the soil about its roots, save the crop; and it is equally beneficial in a similar way on grass lands. On light soils the loosening effects of frequent freezing and thawing are more or less avoided by an autumn rolling. Grass land cannot be too heavily rolled; and on all light lands under tillage the use of the roller is indispensable for closing the pores and preventing the evaporation of moisture.

But while rolling is of much benefit on light, porous, and lumpy soils, it is injurious on wet clays, except in dry weather, when they are lumpy after plowing. Rolling a stiff soil when wet renders it more difficult of cultivation, by pressing the particles still more closely together, and preventing the admission of air. Even light arable lands require the ground to be dry when rolled, if for no other reason than that otherwise the soil will adhere to the roller. Grass land, however, is best rolled in showery weather.

Using the same power in each case, more land will be rolled in the same time on grass than on a wheat seed-bed; and more on a wheat seed-bed than on rough fallow land. A light one-horse roller, covering about six feet in width, will get over twelve to thirteen acres on grass land, ten acres on a wheat seed-bed, and eight or nine acres on fallow land, in a working day of ten hours. A two-horse roller should get over twelve to fifteen acres on grass, ten to twelve acres on a wheat seed-bed, and ten acres on fallow. A clod-crusher, drawn by three horses, will accomplish six to eight acres per day.

Hoeing.—This operation is proceeded with while the crop is growing, and it fulfills two important objects. First, it extirpates weeds and keeps the land clean; and secondly, it stirs, loosens, and pulverizes the surface soil. The extirpation of weeds is of course indispensable to good cultivation. But the second principle of hoeing is if possible still more important. Deep and continuous hoeing is wonderfully effective in promoting the growth of plants. It prevents the soil reverting to its natural solidity, admits air and water, and by breaking and subdividing it, causes it to retain moisture and to present innumerable surfaces and fresh particles to the young roots. The effect is visible in the faster growth of the plants every time the earth is stirred about them.

Hoeing, however, can only be practised in the case of crops in drills or in hills. Broadcast work is thus incompatible with thorough cultivation, even in the case of grain crops. If horse-hoeing is intended among the grain crops, the drilling should correspond with the horse-hoe to be used. Drilling is equally indispensable to all hand-hoeing.

Steam Cultivation.—In many cases tillage by the wealthy farmer may, in part at least, be advantageously performed by steam power. It (1) gives cheaper, deeper, and more efficient tillage than horse power; it (2) enables the work to be done with rapidity and at the best season; it (3) enables land to be more quickly and effectually cleaned and kept free from weeds; it (4) promotes good drainage by rendering tenacious soils more friable and porous; and it (5) not only effects a considerable diminution in the number of horses, but, by relieving them of their heaviest work, enables you to keep those which are still necessary at less expense.

Of the two main systems of cultivating by steam, the double-engine system necessarily involves the largest outlay to begin with; but where the farm is large enough to afford a reasonable amount of work for the tackle, it will cultivate at a less cost per acre than the single engine tackle.

Depth of Cultivation.—The proper depth at which to cultivate must depend chiefly upon the nature and condition of the soil, though partly also upon the kind of crop to be grown. Wet lands should not be plowed deep until they have been thoroughly drained. Alluvial soils and deep clay loams, where the surface and subsoils do not materially differ, can scarcely be tilled too deep. Thin soils, however, should not for present profit be plowed below the layer of mould; but their ultimate fertility and capacity may be greatly increased by subsoiling and heavy manuring for a series of years. It takes twice as much manure to fertilize land when it is plowed to a depth of ten inches as when it is plowed five inches; and the converse is equally true—that by plowing only five inches the soil will be exhausted much quicker than when the plowing is ten inches. But whether it involves the necessity of additional manure or not, a tillage depth of six to ten inches is vastly preferable to a less depth. Von Thaer estimated that each inch of mould between six and ten inches increased the value of the soil eight per cent.

The importance of deep tillage may be inferred from the great depth to which the roots of some plants will penetrate the soil, when conditions favor their doing so. And a deep soil is as beneficial for the supply of moisture during dry weather, as to give room for the roots of plants to extend themselves. Further, the deeper stratum not only renders the soil less subject to drouth, but it makes it a better retainer of heat, and furnishes a better medium for the action of all the agents engaged in promoting the vigorous growth of plants.

Deep and thorough tillage, therefore, is to be extolled as a general principle. Still, while it is useful to all crops, it is of more direct importance to some plants than to others. Root and green crops are the ones which benefit most directly by deep cultivation of the soil. As these crops usually follow grain crops, it thus becomes desirable to give the deepest tillage on the grain stubbles. When the land has been plowed or cultivated deep in preparing for the green crop, deep stirring for the subsequent crops of the rotation may be not only unnecessary but often injurious, as being unsuited to the habit of growth of the plant under cultivation.

Amount of tillage requisite.—Good husbandry gives to every soil and crop its proper tilth. The stiffest and poorest soils require the greatest amount of tillage. Light soils, however, are rarely over-cultivated. As Tull, in his philosophy of tillage, has pointed out, much plowing and pulverizing of a naturally light soil will not make it more loose and open, but have the contrary effect, making its natural porousness less, and its density greater.

It is possible, of course, to have a soil too loose, for it must have a certain consistency to retain moisture and support plants ; but too great looseness is a rare fault, and one not without its remedy. By harrowing the land while it is still damp, and by heavy rolling as it becomes drier, the necessary degree of firmness may always be obtained.

The soil is more frequently too open ; but that indicates either a want of sufficient tillage or an injudicious application of it. In dry weather clay soils are brought to the finest tilth with the least labor, by harrowing immediately after plowing or cultivating, and accompanying this operation, when necessary, with the use of the roller. In a similar season, light and dry soils must be sown and finished up as quickly as possible after plowing. In a wet season, the best tilth is obtained by harrowing when the soil is in the stage "twixt wet and dry."

The mechanical condition of a good seed-bed should be regulated more by the kind of crop to be grown than by the character of the soil. We know the importance of a solid bottom and a fine surface for barley. Nor will wheat and oats grow in a very loose subsoil, though a fine top is of less consequence, to wheat at least. Root crops, on the other hand, require a seed-bed which is neither firm nor loose, but fine and deep. Grasses and clovers flourish best on a firm hard soil with a fine surface.

Stubble cleaning and autumn cultivation.—The two great objects of tillage, pulverization of the soil and destruction of weeds, are greatly facilitated by stubble cleaning and autumn cultivation.

As the weeds are in their weakest condition just after the grain is harvested, that is the time to attack them. The most effectual plan of doing so is to cultivate the stubbles. Previous to this, however, deep-rooted weeds, like the dock, should be pulled; and couch-grass, where it occurs in patches, should be forked out by hand. Then the broad-share cultivator may be run over the field, taking care not to cut the roots of the remaining weeds, but to cut under them, and so to loosen the soil, and the hold of the weeds upon it, that they can be shaken out by the harrows and gathered into heaps. It is not necessary to burn the weeds if there is any objection to that plan. They might be left on the ground, if dead, to decompose; but as that will interfere with the work which has to go on, a compost may be formed of the weeds with quick-lime, road-scrapings, etc. The quick-lime, if used in the proportion of one-eighth, will speedily decompose the weeds, and the compost will be ready to apply to the land in the spring.

Pulverization of the surface soil will be brought about by these operations, but clay soils, generally, will be further benefited by deep plowing and exposure to winter weather and frosts. The autumn tillage, however, as well as that at other seasons, should conform with the requirements of the cropping which is to follow.

Keeping the soil covered.—Land is not cleaned and tilled with the object of being left bare. Let, therefore, the stubble cleaning and autumn tillage be done early enough to admit of a catch-crop, if not a regular winter crop being sown. The Rothamsted experiments have clearly demonstrated the desirableness of this course. When there is no vegetation, or even when there is vegetation, during excessive drainage, nitric acid is lost in large quantity through the drains. The remedy for this is to sow the newly-cleaned stubbles with clover, mustard, rape, winter rye, or, in mild climates, to plant cabbages. The catch-crop will pay well for growing, and the land will be clean after its removal in spring. It will then require comparatively little labor to prepare the soil for the summer crop; whereas, when all the cleaning remains to be done at that period, it is so laborious and difficult that it is seldom well done, while the proper season for sowing is often lost through the work not being accomplished in time. Nor must it be forgotten that keeping the soil covered is not everything; for, as Sir J. B. Lawes points out, the power of vegetation to utilize the nitric acid in the soil is much diminished if there be a deficiency of available mineral constituents. This deficiency is to be prevented or made good by stubble cleaning, autumn plowing, and exposure of the soil; and fertility is to be retained by concurrent good management in cropping.

Water-furrowing.—It is of the utmost importance in the cultivation of stiff soils, whether they be underdrained or not, that the field be laid up in lands or ridges before winter, and that the intervening furrows be well cleaned out. Where clay land cultivation is well understood, every field is not only plowed in narrow lands before winter, but diagonal furrows are so taken across the slope as to cut over these ridge furrows at intervals of fifty or sixty yards; and these cross furrows are well cleaned out by the spade, and so connected with an outfall to the ditch as that it is impossible for any rainfall to pond anywhere in the field.

CHAPTER VII.

HOME MANURE.

General and Artificial Manure.—FARM-YARD MANURES: Management, Application, Valuation.—GREEN MANURES.—SHEEP FOLD—COMPOST.—LIME.

We include in this chapter all the home resources of the farm in connection with this subject;—Lime also, as being part of the system on which the maintenance of fertility often depends. The auxiliary and artificial manures now generally employed are the subject of another chapter.

Manures supply the soil with ingredients required by plants which are deficient in the land either by reason of the exhaustion consequent on annual cropping or from original poverty of composition.

All fertile soils can yield from their stores of natural fertility a certain amount of produce; and rent, as Sir J. B. Lawes has recently pointed out, may be described as being paid for the right of annually removing a certain portion of the fertilizing matter in the soil. If the crop of the year be left on the land, the fertility of the soil is increased, for some of it is derived from the air. If it is continually removed, however, the loss will exceed the natural increment; and the soil will ultimately fail, unless the substances removed are restored from some other source in the form of manure. The poorer the soil, the more complete must be the restoration of the ingredients carried away in the crops, if fertility is to be maintained or increased. But even the best soils are made to yield larger crops with manure than they can do without it.

Practice and experiment in the growth of crops have shown that nitrogen, phosphates, potash, and lime, in assimilable form, are the substances which most strikingly benefit land; and chemical analysis has determined in a measure the varying proportions in which different crops draw upon these and other constituents of the soil.

Acting on this knowledge, chemists have given specifications for the preparation of manures for all the different crops, these schemes being professedly based on the composition of the crops themselves. But manuring on this principle would often cost more than the consequent increase of the crop would repay; for it makes no allowance for natural fertility, and it makes no distinction between the composition of the crops grown and the composition of the produce sold off the farm. We know that soils are of very unequal fertility, that some have an unlimited food-supply compared with others, and that it is only the materials sold off the farm that the maintenance of fertility requires to be restored. More than this, crops differ greatly in their capability of self-supply. Take, as an example of the latter characteristic, the relations of wheat and clover to nitrogen. Chemical analysis shows that clover contains more nitrogen than wheat; and yet the wheat finds its nitrogen with difficulty, while the clover seems to have a power of self-supply in this particular. Thus, in defiance of the chemical composition of the two crops, the farmer's practice, when he manures wheat liberally with nitrogen and gives little or none to clover, is justified. Economic manuring must supplement the plant's weakness, while it makes good the deficiencies of the soil.

A general manure contains all the constituents of the crop, or at least all those in which soils are most deficient; but it by no means follows that every substance which may act beneficially as a manure ought to be applied. If a soil is deficient in one particular element, and contains all the other requisites of fertility, that one substance may act as beneficially when applied as though it were a manure containing all the constituents of the crop. The crop in this case is thrown upon the natural resources of the soil for all its other elements. After a heavy dressing of one substance, that substance may not be required for several years, but some other substance may be needed ; and this all the more because the larger crops now grown will exhaust such other substances more rapidly than the smaller crops did previously. By persisting in the exclusive use of a special manure, an ultimate exhaustion of the soil is inevitable. Judiciously used, special manures are the agents which bring into useful activity the dormant resources of the soil ; they restore the proper balance between its different constituents, and supply the excessive demand for some particular elements. Still, the application useful on one soil may be quite useless on another, and the application may be useful on a soil in one season and useless in another.

A general manure may be used year after year in a perfectly routine manner, but where a special manure is employed, the importance of watching its effects and altering it as circumstances indicate, cannot be overestimated. This forces upon us the necessity for studying the succession of manures as well as that of crops.

In many cases in which ammonia when first used proved beneficial, it now begins to lose its effect, and the reason no doubt is, that by its means the phosphates existing in these soils have been reduced in amount, while the ammonia has accumulated, so that change of manuring is needed.

Artificial Manures.—Farm-yard manure is a "general" manure; whereas all artificial manures are more or less "special" manures, some of the most successful of them being deficient in a great many of the most important elements of plant-growth. In addition to the special food-supply yielded by them, they are, as a rule, more active and give quicker returns than farm-yard manure; so that however rich the latter may be in the constituents of crops, it is impossible, in the present condition of agriculture, to do without large supplies of artificial manures.

The late Mr. Pusey experimented with a view to discovering the extent to which farm-yard manure could be profitably used. One acre of land, without manure, yielded fifteen and a half tons of mangels; a second acre, with thirteen tons of farm-yard manure, yielded twenty-seven and a half tons of mangels; a third acre, with twenty-six tons of farm-yard manure, yielded twenty-eight and a half tons of mangels; and a fourth acre, with thirteen tons of farm-yard manure and two hundred pounds of superphosphate, yielded thirty-six tons of mangels. So that while thirteen tons of farm-yard manure gave an increase of twelve tons in the crop, twenty-six tons of farm-yard manure gave only an increase of thirteen tons in the crop, and thirteen tons of farm-yard manure with two hundred pounds of superphosphate gave an increase in the crop of twenty and a half tons per acre.

The artificial manure in this case is shown to have acted as a powerful and economical supplement to farm-yard manure when the latter was used in moderate quantity. But there are many cases in which artificial manures must be solely relied on. Where land is very steep and hilly, and outlying, it is often cheaper to purchase light and portable manures; and to supplement their use in such cases, not with the manure-cart, but by feeding sheep on the field on the roots or other green-crop grown on the land.

The importance of artificial fertilizers cannot be over-estimated in regard to the maintenance of fertility on poor lands. Many of them have acquired also an additional value on account of their special character, and their special action on the quality of various crops grown for industrial purposes, as sugar-beet, flax, etc.

The action of manures is not, however, fully explained by their affording a direct supply of plant food; for many of them operate indirectly to feed crops by their chemical effects upon the soil. Thus, farm-yard manure, in undergoing decomposition yields a supply of carbonic acid, which may act on the mineral constituents and liberate their elements. Many mineral manures also, common salt, gypsum, and other saline matters, may react on the soil, converting potash and magnesia, for instance, into soluble forms, and thus giving the same result as would follow an immediate use of the last-named substances.

Again, certain manures which are used in large doses influence the fertility of the soil by amending its texture, or otherwise modifying its physical characters—as we have already seen in the case of marling and mixing of soils. Farm-yard manure is of great benefit in this respect, both on heavy clays and on light sandy soils; for in the one case it diminishes tenacity, and in the other it lessens porosity and helps to retain moisture.

Farm-yard manure is a mixture of the dung and urine of farm animals with the straw and other matters used as litter. It is regarded as the typical manure, both because it is a "general" manure, and on account of its influence on the texture and general character of the soil to which it is applied. Still it is not a perfect manure. It contains, no doubt, all the elements of plant-growth; but these are not always present in the best proportions. To prevent a deficiency of one element, it has to be employed in such large quantities as to furnish other elements more or less in excess of what is actually required by the crop. Its great bulk also makes it extremely expensive to handle. It is, moreover, exceptionally liable to waste, and it yields its results very slowly.

In a ton of ordinary farm-yard manure there is contained about thirteen pounds of nitrogen, ten and a-half pounds of potash, and ten and a-half pounds of phosphoric acid. The per centages are of course, variable. Mr. Warington, in the "Chemistry of the Farm,"* puts the amount at nine to fifteen pounds of nitrogen, nine to fifteen pounds of potash, and four to nine pounds of phosphoric acid. The conditions affecting the composition and quality of the manure are—(1) the kind and condition of animal producing it; (2) the food of the animal; (3) the kind and quantity of litter used; and (4) the care bestowed upon its after-management.

1. *The Animal.*—The quality of the manure varies, not only with the class of animal—horse, cow, sheep, pig, etc.—which produces it, but with the age and character of the animal. An adult animal takes comparatively little of the nitrogenous and ash elements from the food, because what it chiefly requires is the carbonaceous matter to keep up respiration and to form fat. A young and growing animal has more varied wants to supply in the formation of both bone and muscle, and therefore it re-

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quires far more of the nitrogenous and ash elements in its food to accomplish this growth, in addition to what is necessary to sustain the vital system and to lay on fat. The same is more or less true of breeding animals, and of animals producing milk and wool. Unless both these and the young growing animals are fed on food rich in nitrogenous and ash elements, the manure from them must be comparatively poor. In the case of the mature animal, however, the manure is not materially less fertilizing than the original food.

2. *The Food.*—More important even than the kind of animals as affecting the quality of the manure, is the food used in feeding them. There is a certain amount of waste tissue thrown off by the animal which goes into the manure, but, speaking generally, the excrement represents that portion of the food which is not used by the animal. The extent to which the constitutents of the food are made use of by the animal will depend on the digestibility of the feeding substance, and on the assimilative power of the animal for the food in question. Oil-cakes yield the richest manure; then come beans, peas, malt-dust, bran, clover hay, cereal grain, meadow hay, roots, and straw, in the order named.

3. *The Litter* is an important part of farm-yard manure, not only on account of the manure matters contained in it, which are considerable, but also as affecting the texture and consequent fermentation of the manure. The quantity of litter should be sufficient to absorb and retain the greater part of the liquid manure, and the surplus, if any, should be pumped up at intervals and distributed over the manure so as to keep the whole in a proper state of moisture. If the litter is deficient, the manure becomes too moist, and the most valuable part drains off, unless means are taken to collect it in the liquid tank. Whether the manure is too moist or too dry, fermentation is equally checked; in the former case

by the exclusion of air, and in the latter case by the want of moisture.

Management of Farm Manure.—Air and moisture are both essential to the proper fermentation of manure. If it is too dry, it burns, gets "fire-fanged," white and mildewed; and the high temperature of the manure promotes the formation of carbonate of ammonia, which is volatile and easily escapes into the air. This occurs when the temperature exceeds eighty degrees F. But when the manure is kept moist and the temperature low, fermentation stops with the formation of organic acids which take up ammonia. The salts thus formed are present in the black decomposed dung, and the ammonia in them is in a soluble form, but not volatile. A strong smell arising from the manure makes it evident that a wasteful fermentation is going on. But this fermentation is easily controlled. A quick fermentation will be induced by placing the manure lightly in heaps so as to allow the air to get at it; a slower fermentation, by treading the manure down firmly, as in carting over it; and a cool fermentation by keeping the heap moderately moist. Liquid manure should be used either when it is necessary to moisten the heap, so as to check excessive fermentation, or, unless it be very dilute, just before carting the heap on to the land.

The waste of farm-yard manure may arise from two causes—(1) from excessive supplies of water, as rain falling on and washing it; or (2) from volatilization, or overheating, and the consequent escape of ammonia.

The waste by water is generally recognized, but not sufficiently guarded against; and as a consequence the manure is wasted by rains, soakings, and drainage, which carry off the very essence of it. Where no means are taken to preserve or retain this portion, the loss under ordinary circumstances amounts to from one-third to one-half of the whole value of the manure. The soluble nitrates are washed away by the rain, and the loss of course is greatest in rotten manure, which contains a great deal of its nitrogen in a soluble condition.

The loss by volatilization is not so great. Where the manure is kept in a proper condition as to temperature and moisture, little ammonia will escape into the air so long as the manure is not disturbed by turning, as during fermentation organic acids are produced in such abundance as to combine with the greater part of the ammonia, and form soluble salts of ammonia.

Manure made under cover is preserved from waste by rainfall and drainage; but there is danger of it becoming too dry if the litter is abundant, unless it is moistened at intervals. To feed cattle in covered yards, taking care to spread the litter evenly, and not to supply more than is sufficient to keep them dry, is a great economy so far as their manure is concerned. Box-fed manure and manure from roofed yards have been proved often enough to be greatly superior to that which is made in yards which receive, not only the rainfall proper to their own area, but that of adjoining roofs unprovided with eaves and down-spouts for its removal.

When manure heaps are formed, a thick layer of dry soil, ditch cleanings, vegetable refuse, or peat should be laid down for a bottoming, and the earth or other admixture should be interstratified in layers with the manure throughout, so as to absorb any liquid which may tend to escape from it; and the whole should also be topped with a firm beaten layer of earth in order to exclude the rain. Dry peat is an excellent substance for mixing with manure, as it not only absorbs the liquid portions of it, but somewhat fixes the ammonia. A good peat will absorb about two per cent. of ammonia, and when dry will still retain from one to one and one-half per cent., or nearly twice as much as would be yielded by the whole nitrogen of an equal weight of farm-yard manure.

Gypsum, charcoal, and lime are sometimes added to manure heaps with the view of fixing their ammonia; but where the management of the manure is otherwise good, these are not much required. Chalk and lime are found to have a very good effect in preventing escape of ammonia from farm-yard manure, provided it is fresh manure. Applied to rotten manure, caustic lime causes a great loss of ammonia.

As far as possible the formation of field manure-heaps is to be avoided; but if they must be formed, the practice of turning the manure should be avoided. The labor of doing so, is mostly lost, and much manure is wasted. It is best in every sense to cart the manure direct from the yards upon the land and spread it at once. The questiou of immediate plowing in, or covering it, is of less consequence than has generally been imagined; but on light soils the practice of immediate plowing under is advisable.

We must add, as a somewhat disheartening comment upon the whole of these directions and suggestions, the conclusions of the most experienced agricultural chemist of the day.

"I am bound to confess," says Sir J. B. Lawes, "that I am just as helpless in regard to the management or improvement of manure as the most old-fashioned farmer. It is of no use fixing ammonia where there is hardly any to fix. It costs nothing to look at the dung with the idea of doing something to it; but you certainly cannot touch it without going to some considerable expense. I, for my part, am content, therefore, to let it alone. All labor expended on dung adds certainly to the cost, but it does not add with the same certainty to its value.

"As I grow a good many mangels," he goes on to say, "I apply the greater part of the farm-yard manure to this crop, my practice being to open out the furrow and apply about twenty tons per acre, then, after earthing up the furrows, I proceed to drill the seed upon the top. If I did not grow turnips, I should apply the dung in autumn to clover or grass. This, of course, would involve exposure to the atmosphere, but I should not fear much loss on this account, or, at all events, I do not think there would be more by this process than by any other."

Application of Farm Manure.—If farm manure is applied in autumn, there need be no fear of loss from ordinary rains, on stiff land at least. The time of year, however, as well as the mode of application which may be best, must depend on what crop it is to benefit most, and on the course of cropping.

For potatoes, beans, turnips, and other fallow crops, the dung may be put on the stubbles without much risk of loss before they are broken up; or it may be applied in the manner already described by Sir J. B. Lawes for his mangel crops, at the time of planting or sowing. Where the land is to be worked on the flat, the former practice is preferable, provided the dung is in stock early enough. In England potatoes are never grown without manure; mangels and beans seldom are either; but turnips are frequently grown with the aid of artificial manures only, the land in this case benefiting by the sheep-fold afterwards. For potatoes, mangels, and beans, fifteen to twenty tons of dung are usually applied per acre; and in most cases this is supplemented with two, three, or even five hundred pounds of light manures. For turnips about ten tons of dung and the above quantities of auxiliary manures are reckoned sufficient.

For the wheat crop, the manure is applied on the clover lea before plowing. Some prefer to manure the clover before the first cutting, others between the first and second cutting; and others again not until immediately before the clover lea is broken up. The quantity applied is usually from ten to twelve tons per acre.

On meadows and grass lands, autumn manuring is best, but it is not desirable to use fresh and unrotted dung in this case, and it is best applied in the form of compost. From ten to fifteen cart-loads per acre may be given on grass land, according to the length of time it is intended to last.

The old plan of bestowing all the manure for a rotation on one crop is now being less followed. Although some crops benefit more by an application of dung than others, it is deemed better to use it oftener, and to give less of it at once; and as only a given amount can be produced for each acre, the smaller dressing has to be supplemented with artificial manures.

Green Manures.—This is the term given to crops which are grown for the purpose of being plowed in on the land which produced them. This was once a common practice, but the availability of commercial fertilizers, combined with the high prices obtainable for beef and mutton, has rendered the farmer more careless than he once was of the slower and more natural methods of maintaining or increasing fertility.

By plowing in a green crop, the surface soil is enriched not only by the elements which the crop derived from the air, but also by mineral and vegetable matters which were brought up by it from the subsoil. The green crop thus acts the part of a gatherer of plant food, and makes it easier for any crop sown after this green-manuring to get its supplies from the decomposing vegetation present in the soil.

The plants best adapted for green-manuring, are those which derive their support principally from the air, which grow rapidly, which cover the ground well, and whose roots penetrate deep, and ramify extensively throughout the soil.

Among the various plants grown for green-manuring are white mustard, buckwheat, rye, rape, vetches, *Trifolium incarnatum*, and common clover. In many countries spurry, borage, and white lupin, are also largely grown for the same purpose. Many of these crops, when plowed in green, are, weight for weight, almost as good as farm-yard manure, containing large quantities of nitrogen, phosphoric acid, and potash. The great weight of decomposable vegetable matter contained in the root as well as the leaf of a crop, grown for being plowed in as manure, is to be considered in estimating its effect as a fertilizer. There can be no doubt that to this especially is due the fertilizing effect of a clover stubble when plowed in as a preparation for the following wheat crop.

Eight to twelve tons per acre may be grown of any of the crops we have named with the aid of guano. White mustard comes to maturity in six or eight weeks, and two or three crops of it might be grown on the same land in a single season, after an early summer crop of peas and potatoes. Only a light plowing is needed, and less than a peck of mustard-seed will seed an acre, at a trifling cost. Some of the other crops are not much less rapid growers, and are also inexpensive to cultivate.

Green-manuring produces the greatest effect on light sandy soils in dry climates; but it is profitably practised also on heavy soils. The green crop should, if possible, be plowed in just before the time of flowering, or at all events after it has arrived at considerable growth. The season of the year for plowing in must depend upon the nature of the crop; but the operation is best performed in the heat of summer, as the conditions for rapid decomposition are then actively present, after the plants are turned in. To cover them effectually, they require to be first heavily rolled. A skim coulter should be used in the plow that is employed, and the plowing should be deep enough to retain moisture about the decaying plants.

The Sheepfold.—In districts where bare summer fallows are adopted, the practice of folding is carried on very differently from where green crop cultivation prevails. The method there is to bring the flock from the pasture, where it is fed by day, and fold it upon a fallow by night. When one fold is sufficiently manured, another one is enclosed, the hurdles being shifted daily.

The flock under this system is a mere working machine, whose chief purpose was that of a manure carrier. It is probable that more, in mutton and wool, is lost in this way than is gained in manure. Nor is that the only objection to this system. It is made the means of enriching one part of the farm at the expense of another; as Mr. Bakewell put it, it robs Peter to pay Paul. The grass land is starved to feed the arable. This is the common practice in the neighborhood of the Sussex downs, where farms include a stretch of the down land as part of their area.

Another method is to confine the flock altogother on the fallows, and feed with tares, clover, or other forage plant brought to it. The sheep are better off under this system; but it incurs a great deal of labor in cutting and carting forage; and it starves the land which grew the crop. Folding is now more generally practised on land under roots or green crop, where the sheep feed at their ease, and manure the ground at the same time.

To eat off a crop with sheep is theoretically less enriching than to plow it in green; and if the soil is poor, thin, sandy, and deficient in organic matter, plowing in green crops will be a very advantageous method of improving it. But even on such soils, when mutton or wool is an object, it may be better to feed off the crop, and enrich the ground by consuming quantities of cake or corn along with it.

On light soils, sheep-folding is in many cases universal as a preparation for wheat; and it is the chief dependence in all districts where the quantity of farm-yard manure is insufficient. Poor clay may likewise be speedily rendered fertile by heavily folding in summer time and dry weather with sheep fed on cake, grain, and hay, in addition to vetches, cabbages, or other green crop brought to them. The practice is often as advantageously followed on grass land as on arable. On wet, undrained land, and stiff clays, folding is injurious, unless it is done in very dry weather.

An acre of good clover may feed more than one hundred sheep one week; and an acre of turnips may feed two hundred and forty sheep for the same period. Say that a sheep consumes, and wastes together, twenty-eight pounds of roots daily. Then eighty sheep will consume one ton daily; and two hundred and forty sheep will feed off a crop of twenty-one tons in a week.

Composts are mixtures of fertilizing substances, which, being allowed to undergo chemical changes for a considerable time in heaps, become more valuable than they could have been if applied separately. Peat, road-scrapings, clearings of ditches, weeds, leaves, lime and farm-yard manures, are the substances used to form composts.

Since the introduction of artificial and light manures, the mixing of heavy materials, earth and lime, etc., with other manuring substances seldom pays for the labor expended.

On the other hand, many of the artificial manures are best applied to the soil in the form of compost, *i.e.*, mixed with some bulky material of less value in order to its more even distribution.

Lime.—Quick or burnt lime may be said to exert a three-fold influence as a fertilizer. It is a direct source of plant food ; it unlocks and renders available the stores of inert food, both mineral and organic, contained in the soil ; and it ameliorates the texture of clays.

As all crops require a certain amount of lime, in order to carry on and perfect their growth, a soil deficient in this mineral substance can never be a very productive one, until the deficiency is made good.

It is in its second character, perhaps, that lime does its most important work. It decomposes all kinds of vegetable matter in the soil and corrects any acidity due to the presence of organic acids. It assists to decompose certain salts whose bases contribute to the food of plants, and it acts in facilitating nitrification. In all these respects it may be said to digest and prepare general plant-food, though it does not in itself furnish more than one of the ingredients which plants require from the soil. It also helps to retain certain soluble manures in the soil, and it economizes the use of potash ; certain crops, such as roots and clover, where potash is not abundant in the soil, having to some extent the power of utilizing lime in its place. When we add that lime improves the quality of grain, grasses, and other crops, the finer grasses on certain lands refusing to grow until the land has been limed ; that it is the only known cure for "finger and toe" in turnips; that it hastens the maturity of crops; and that it destroys insects, and checks the growth of moss and weeds in the soil—it will be seen how various and important is the work it performs.

The effect of lime on the mechanical texture of many soils is also great. It pulverizes and lightens strong soils, at once improving their drainage and rendering them easier tilled. On peaty soils it reduces the excess of organic matter. It also improves the texture of light soils, provided an overdose is not applied, even when they contain but little vegetable matter; the avidity of the lime for moisture, added to the chemical changes brought about by it, having the effect of increasing their absorptive and retentive powers in a considerable degree.

The quantity of lime applied need not be large, but may vary, according to circumstances, from 0.05 to .5 per cent., by weight, of the cultivated soil. On a soil ten inches deep an application of one ton per acre would represent a dressing of 0.05 per cent.; and ten tons per acre will equal .5 per cent. In actual practice more than five or six tons per acre is seldom applied. This quantity may be required for strong land, or for land containing much organic matter in an inert state; but for light land with little vegetable matter, occasional dressings of one to two tons per acre will, in most cases, be found sufficient.

A deep soil requires a heavier dressing of lime than a shallow soil; and deep tillage will call for larger applications than where the cultivation is shallower. A sandy soil requires less lime than a heavy clay; and soils poor in vegetable matter will need smaller dressings of lime than soils that are rich in organic matter. A small quantity of lime will have greater effect on drained lands than a larger dose on wet and undrained land. Green crops will generally benefit more by lime than corn crops.

There are few soils in which some lime is not already present; but the smaller this quantity, the better, as a rule, will the soil pay for an artificial application. The form in which the lime exists in the soil, is, however, important. If in the form of silicate, or even gypsum, it will pay better to add lime to the soil, than if the lime present had existed as carbonate. It will also pay better to apply lime to land that has never been limed, than to land where it has been previously applied. The quantity of lime necessary, as well as the kind of lime that should be added, will thus be much influenced by the composition and texture of the soil. Small dressings at frequent intervals are now the rule. Instead of applying four to eight tons per acre once in fifteen or nineteen years, as formerly, it is considered more economical, on land which has been previously limed, to apply it every six or eight years in quantities not exceeding one to two tons per acre.

Where the opposite course is adopted there is considerable waste and a gradually diminishing effect. A certain quantity of the lime is dissolved and removed by drainage waters, and the remainder in a few years sinks below the cultivated depth; or chemical changes take place which render it effete. On arable land the plow for a season or two brings it back to the surface; but after a time it gets beyond the depth of the plow, and is as much lost as if the land had not been cultivated. This strong tendency of lime to sink into the subsoils ought to teach us, when liming land, not to plow the lime in, but to keep it as near the surface as possible. The land should be plowed first, then the lime spread, and simply harrowed in.

Evidence recently supplied shows that the effect of lime is most durable upon pastures that are grazed: it lasts longer upon good than upon bad land; and longer upon clays and heavy loams than upon light land. On the same authority we are told that a full dressing of lime endures frome seven to thirty years. This is not very definite, but with the liability to so many conflicting influences, these extreme differences are easily accounted for.

On arable land the lime should be applied during the fallow year. It matters little whether this is done in autumn or in early spring. Convenience of carting, and opportunity for getting the lime on the land will be the chief guides here. The lime slakes best and quickest when laid down in small heaps and slightly covered with fine soil. This saves re-filling and re-carting. If the heaps are put down ten yards apart each way, there will be forty-eight or forty-nine heaps per acre; and fifty-pound heaps at that rate would give a dressing of twenty-four hundred pounds per acre. If the heaps are placed five by five yards apart, the dressing will be four times as much, or nine thousand six hundred pounds per acre.

Except on old mossy land, lime is best applied to grass land in the form of compost; and the application should be made in early winter, so that the lime may work into the vegetable surface before spring growth commences. The lime may be previously slaked, or a compost formed, in a corner of the field. It should not be put out on the land in small heaps, as in the case of arable land, but spread direct from the cart.

Limestone and Lime.—Within a few years the extraordinary claim has been made, that finely-ground limestone was not only of equal value with, but was actually superior as a fertilizer to lime. This assertion by dealers in ground limestone, and by those who had grinding machinery for sale, was apparently sustained by the certificates of persons who claimed to have made comparative trials of limestone and lime. This newly discovered value of limestone, being contrary to all previous experience, and directly opposed to the known chemical properties of the two forms of lime, was the subject of numerous inquiries by the readers of the "American Agriculturalist," to which the editors of that journal made the following reply:

Limestone is a most widely distributed mineral, one of its purest forms being known as marble, and is found almost all over the United States of various qualities and degrees of purity. It is a carbonate of lime, that is, lime combined with carbonic acid. If a fragment of limestone is placed in a glass of water, and a little strong acid is added, the carbonic acid is set free, and we see it pass off as bubbles rising through the water. Limestone is so slightly dissolved by water that it is tasteless. It takes one thousand six hundred parts of water to dissolve one part of limestone. Water, in which there is much carbonic acid, dissolves a considerable amount of carbonate of lime. If a small piece of limestone be kept at a strong red heat for some hours, it will be only about half as heavy as the original stone. What has it lost in the burning? If tested with acid, as before, no bubbles of gas will be given off. The heat has driven out all the carbonic acid; it is no longer a carbonate of lime, but simply lime (an oxide of the metal calcium, or calcic oxide, as the chemists have it). Limestone burned in kilns produces lime, often called quick-lime. If a lump of freshly burned lime have water gradually put upon it, it soon becomes hot; in a little while it swells up, cracks, and falls into a very white powder; though much water has been added, the powder is quite dry. The water has united with the lime, making a solid, caustic or slaked lime. Lime exposed takes up moisture from the air, and we have air-slaked lime. Slaked lime with enough water forms whitewash, or "milk of lime." On standing, the greater part of the lime will settle, leaving clear lime-water—a saturated solution of lime; that is, the water has taken up all it can dissolve, for at ordinary temperature it requires several hundred parts of water to dissolve one part of quick-lime. If clear lime-water be placed in a glass, and with a straw or pipe-stem the breath be forced into it, the lime-water will soon become cloudy, and then milky. Set the glass aside, and a fine white powder will settle at the bottom, leaving the water clear above. The breath contains carbonic acid; this, when forced into the lime water, unites with the lime, forming carbonate, the same as unburned limestone, which, being little soluble, separates as a white powder. If we continue to breathe into the lime-water after it has become milky, it will soon become perfectly clear as at the start. The continued breathing supplies more carbonic acid than is needed to convert the lime into an insoluble carbonate; the excess of carbonic acid in the water redissolves the carbonate. Heating this solution drives off the excess of carbonic acid, and the carbonate of lime will be deposited again. Carbonic acid is always present in the atmosphere, and when slaked lime is long exposed, it takes up this acid and slowly becomes carbonate of lime.

Why we use Quick-Lime upon the Land.—All cultivated plants contain lime in their ashes, and it is considered necessary to their proper growth. But soils generally contain enough lime for the use of the plants, and we apply it for its action upon the other constituents of the soil. Lime acts upon and greatly aids the decomposition of organic matter in the soil. It is thought to neutralize the organic acids contained in what are called "sour soils." In a complicated manner it aids in the fixing of ammonia. It also acts upon the inorganic or mineral constituents of the soil, and aids in converting them into forms in which they can be taken up by the plants, especially in liberating potash from its combinations. The effect of lime upon the mechanical condition of the soil is an important feature. Upon heavy clay soils its effect is most marked; the particles lose their adhesiveness, and allow air and water to enter. These are the leading effects that follow the use of lime. In view of the claims made for ground, unburned limestone, it is an important question how far it can produce the above effects. That the unburned limestone will supply the demands of the plant for lime, that it may slowly neutralize organic acids, and help the mechanical texture of the soil seems very probable. But that it will perform one of the most important offices, the decomposition of organic matter in the soil, and convert that into plant food seems improbable, because the ability of lime to do this depends in a great measure upon its avidity for carbonic acid, while limestone being already a carbonate, has no need of more. That limestone can not produce all the effects of lime is shown by the well-known fact that soils underlaid by limestone, and naturally containing a large proportion of finely divided carbonate of lime, are as much benefited by the use of quick-lime as are soils deficient in limestone.

CHAPTER VIII.

AUXILIARY AND EXCEPTIONAL MANURES.

GUANO: Statistics.—Prices.—Valuation.—Application.—BONES: Bone-dust.—Bone-ash.—Superphosphate.—Ground phosphate. — NITROGENOUS MANURES: Nitrate of soda.—Sulphate of ammonia.—ALKALINE MANURES: Potash.—Kainit.—Gypsum.—Common salt.—Ashes.—OTHER MANURES: Soot.—Rape-dust.—Fish refuse.—Blood.—Sea-weed.—Sewage.—Liquid manure. — APPLICATION OF MANURES: Top-dressing.—Value of manures from foods.

Guano.—The constituents of value in guano are (1) ammonia and ammonia-forming compounds; (2) soluble and insoluble phosphates; and (3) alkaline salts. The approximate value of any sample can be arrived at by multiplying the commercial values of these materials by the percentage found of each ingredient. The values of ammonia, phosphoric acid, and potash, vary according to the source which supplies them.

Analyses ought always to be made before purchasing; and if there be reason to doubt the guarantee of the manufacturer, a private analysis can be made afterwards.

Without the knowledge of its composition thus acquired, the best Peruvian guano, rich in ammonia, might be extravagantly employed upon soils that would be almost equally benefited by the cheaper qualities, of which the phosphates are the chief fertilizing ingredients. Upon light soils, especially, ammoniacal guano may be used wastefully, owing to the little obstruction such soils present to the escape of its volatile and soluble portions. The full benefit of these will be better secured in the stronger soils, or in composts prepared with the view of their absorption and retention. In such mixtures guano is used most advantageously. Of itself alone, it may furnish all the ingredients required by the plants; but its activity and evanescence need to be checked ; and on account of its caustic quality, care should be taken that it be not brought in direct contact with the seed.

The quantity of best guano that should be used per acre is generally rated at from three to five hundred pounds, and it should be applied in damp weather so that the rains may gradually diffuse it equally through the soil. No definite rules, however, can be given as to what soil will be most benefited by guano, or as to the necessary quantity to be employed. If used in the compost form it should be mixed, previous to sowing, with four times its weight of good soil; which will avert the danger of injury to the seed and effect a more equal distribution of the manure. For grasses and clovers, ten to fifteen hundred pounds of such a mixture should be sown broadcast in the early spring. This will be equivalent to from two three hundred pounds of the guano. Guano is too soluble to be applied with profit in autumn.

On corn crops no manure has a more powerful effect than guano. It is used as a top-dressing in spring at the rate of three to four hundred pounds per acre. The stronger the land is, the larger the quantity that can be applied with profit.

For turnip and other root crops, as much as three to five hundred pounds per acre of Peruvian guano are often beneficially used on strong land without other manure. Peruvian guano is too stimulating when applied in large quantities to late sown turnips, promoting an excessive luxuriance of leaf, and preventing the formation of bulb. In such cases, phosphatic manures will yield better crops at less expense. It is applied generally to the root crops by sowing broadcast at their seed-time.

Beans and potatoes also benefit by guano, but on most soils it does not possess the power of sustaining the healthy growth of these plants without something else in addition.

Bones owe their value as a fertilizer partly to the phosphoric acid which they contain, and in a less degree to the combined nitrogenous matter which they contain. They are used as manures either in the form of (1) bone-dust, (2) as bone-ash, or (3) after treatment with sulphuric acid.

(1.) Bone dust, or bone-meal as it is sometimes termed, is obtained by crushing or grinding the bones to a kind of coarse powder. The finer the state of division, the more rapid is the action of the manure, and the coarser the particles, the slower its effect.

Steaming the bones previous to grinding them, dissolves out about two-thirds of the gelatine, and occasions a loss of nitrogen ; but they are then easily reduced to a very fine powder, and are thus rendered more effective as a manure.

When bone-dust is prepared from bones that have not been steamed, it is best applied mixed with earth, or some other substance, and fermented. Wet sand, sawdust, stable-droppings, or any substance that will induce fermentation, may be usefully employed for this purpose.

These, mixed with the bones, in the proportion of three to one, and moistened with the drainings from the cattle-yards, will furnish a highly fertilizing manure. The heap requires to be made up in a covered shed, and having been sufficiently moistened, is left to ferment. The mixture is applied to grass land at the rate of thirty or forty bushels per acre; and to arable land at the rate of twenty or twenty-five bushels per acre.

As a general rule, bone manures are better adapted for the lighter class of soils than for stiff land. On some soils their use has been attended with surprising effect; but on others, such as clay soils, for example, as may be already naturally rich in phosphates, the application of bones is of comparatively little benefit.

(2.) Bone-ash is the residue left after burning bones. It consists of the earthy matter of the bone, and amounts to about sixty-six per-cent. of the original weight. It is chiefly obtained from South America, where large herds of cattle are slaughtered, and the tallow melted from the carcass, in which operation the bones of the animal are used as fuel, thus forming the bone-ash of commerce. The essential differences between crushed bones, dissolved bones, and bone-ash, are that while the first contains phosphate of lime and nitrogen, the second contains in addition soluble phosphate, and the third has been deprived of its nitrogen by burning. The bone-ash is chiefly used in the manufacture of superphosphate of lime, which only differs from dissolved bones in that it contains no gelatine or animal matter yielding nitrogen.

(3.) Superphosphate.—By dissolving bones in sulphuric acid they are rendered more available for the first crop, and a smaller application suffices at any one time.

The bones are first ground to powder, and then treated with sulphuric acid of specific gravity 1.66. A sufficient quantity of sulphuric acid is added to every ton of bone-dust, and thoroughly incorporated. In the pasty condition to which the sulphuric acid reduces the bones, it is quite impossible to apply it either by hand or drill ; wood-ashes, peat-ashes, or even dry soil may be used to prepare them for sowing ; but quick-lime, or powdered chalk, must not be mixed with the dissolved bones for the purpose of drying, as the lime would restore them to their comparatively insoluble condition.

By dissolving bones their effect on the turnip crop is greatly increased. Superphosphate is applied at the rate of four to five hundred pounds per acre, when used by itself.

Superphosphate is also prepared by treating bone-ash and coprolite or mineral phosphate with sulphuric acid.

The difference between the effects produced by animal phosphate and mineral phosphate is virtually nothing, but the difference in price is very considerable.

The farmer may manufacture his own superphosphate. An iron tank or a strong wooden vat is used in preparing it. The bone-ash or coprolite powder to be dissolved is put into the tank, and over it is poured one-fourth its weight of water. Afterwards stir and mix well ; then add sulphuric acid equal to about half the weight of bone-ash, or more of mineral phosphate, and again stir and mix thoroughly. The finer the division of the ground phosphate the more rapid and effectual is the process. If ammonia is wanted in the subsequent manure, it can be supplied by an addition of sulphate of ammonia. After removing the superphosphate from the tank, if it is placed in a heap under cover and allowed to remain for a sufficient time, the moisture will evaporate by the heat of the mass. It will lose in weight according to the time it remains in the heap, but there will be an increase in the percentage of soluble phosphate. The same substances may be used for drying the superphosphate, however, as have been recommended for drying dissolved bones.

The soluble phosphoric acid in superphosphate on coming in contact with lime in the soil is rapidly converted into an insoluble form, and consequently it does not rapidly penetrate the soil. This change takes place with certainty in a soil which contains much calcareous matter. A few hours thus often suffices to modify the easy solubility of the manure; and the more rapid the change is brought about the more necessary it becomes to have the superphosphate in as fine a state of division as possible, and well mixed with the soil. The extreme state of division in which, however, this process leaves it, makes it far more soluble in the carbonic acid rain-water than the most finely divided bones or coprolites which had been reduced by mechanical means; and the efficiency of the manure is thus not materially impaired.

It is especially suited as a manure for the turnip crop. If used alone, as much as four or five hundred pounds per acre may be applied with good effect; but on most soils it is advisable to use a smaller quantity; and for mangel wurzels and potatoes it is best applied mixed with one hundred pounds of sulphate of ammonia and two hundred pounds of potash salts. For the potato crop, from four to six hundred pounds of superphosphate may be used, in addition to farm-yard manure, or ammonia and potash salts. As a mangel manure, superphosphate is considerably less effective than guano. On barley it has been largely used as a top-dressing of late years at the rate of about three hundred pounds per acre. The oat crop, too, as grown in the fen districts, receives a dressing of superphosphate with great advantage during the spring. A greater bulk of both grain and straw has thereby been produced, and an earlier harvest is obtained.

Ground Phosphate.—Its value as a fertilizer is derived from the phosphate of lime of which the mineral is partly composed. Coprolites, as to seventy to eighty per cent.

of their substance, are a mixed phosphate and carbonate of lime.

Although there seems to be considerable difference in the results obtained by different experiments, the general conclusion seems to be that the usual difference in the effects produced by soluble and insoluble phosphates is much diminished when the latter are reduced to very fine powder and applied in very large quantities. The powdered phosphate is cheaper than the manufactured manure. But there can be no doubt that an increased use of ground coprolites would result in increasing their cost in the market, and the advantage would thus to some extent be lost.

After fine grinding, the coprolite powder may be mixed with farm-yard manure, either under the cattle or else in the dung heap, and the carbonic acid formed by the fermentation of the dung tends to the solubility of the mineral phosphates by actual superphosphating. Sixteen years ago, Professor Graham pointed out the greater advantage to agriculture of the cheap carbonic acid method of superphosphating than of the dear sulphuric acid method; first, because it was vastly cheaper, and secondly, because it did not give rise to the production of insoluble phosphates.

Ground phosphate requires to be used in much larger quantities than dissolved phosphate, if it is to produce equal results. As a top-dressing on grass land, however, it should only be applied in showery weather, so that the rains may wash it into the soil. For barley and turnips it is harrowed in or mixed with the soil; and there also it is more effective in a moist season than in a dry one; and its efficacy is in all cases greatly enhanced by composting it with the substances mentioned above before applying it to the land.

Nitrate of Soda and Sulphate of Ammonia.—These are the two chief nitrogenous manures in the market, and at present prices the nitrate is the cheaper fertilizer of the two.

"The commercial value of these two substances is based entirely upon the amount of nitrogen which they contain. Having said this, I by no means wish to be understood," says Sir J. B. Lawes, "that the action of the two substances is the same. Both supply the plant with nitric acid, but with the sulphate of ammonia, the formation of nitrate of lime is attended with the formation of sulphate of lime, and with a considerable removal of the soluble sulphate of lime in the soil. Where nitrate of soda is used, an alkali is liberated, which has a decomposing action upon the minerals of the soil. In cases where sufficient potash is not available, large amounts of soda are also taken up by plants when manured with nitrate of soda. We have found soda very largely in pasture sugar beets and mangels, but not in potatoes.

"For some reason which I am unable to explain, the application of nitrate to leguminous plants is more favorable to their growth than the application of salts of ammonia. The herbage of a permanent pasture, where nitrate of soda alone, in one case, and with the addition of minerals in another, is applied every year, is of a totally distinct character from the herbage where salts of ammonia are applied alone, in one case, and with minerals in another. I think, too, we have evidence to show that the organic matter in the soil is reduced more rapidly by nitrate than by ammonia."

Of the two manures, nitrate of soda answers best in a dry season, and sulphate of ammonia in a wet one. They can only be economically applied to land with a growing crop ready to seize on them. It is therefore never advisable, even in a dry spring, to sow these soluble manures as early as the seed. Grain crops should be well above ground, and root crops should be at least thinned and set out, before either ammonia salts or nitrates are applied.

On wheat or grass land one hundred pounds of sulphate of ammonia or one hundred and fifty pounds of nitrate of soda, per acre, may be used as a top-dressing after early spring growth has commenced; and half as much as a supplementary dressing at a later period, if required. The same quantities will often be bestowed with profit on the root and green crops, giving the first dressing about a month after sowing and the second at the time of the last hoeing.

Potash Salts.—These are most efficacious on grass land, if well drained, and on light sandy soils. Grasses, potatoes and turnips are particularly benefited by manures of this class. The chief source of supply is kainit. Potash salts in kainit require to be applied to the soil in autumn, giving them time to dissolve in the soil. From one hundred to one hundred and fifty pounds of muriate of potash, or from six to eight hundred pounds of kainit, per acre, are applied in conjunction with other manures.

Gypsum, or sulphate of lime, is extensively employed as a fertilizer. It enters into the composition of clover, grasses, turnips, and potatoes, but a special application of gypsum to the soil has little effect in our system of farming. It is abundantly supplied to crops, in the common course of culture, in the farm dung and in superphosphate or dissolved bones and other artificial manures.

The value of gypsum as a fertilizer is believed to be partly due to its action in fixing volatile and escaping carbonates of ammonia, and conveying them to the roots of plants. When carbonate of ammonia comes in contact with sulphate of lime, double decomposition takes place, carbonate of lime and sulphate of ammonia being formed. Powdered gypsum may thus be used in stables as a fixer of ammonia. It requires to be in a fine state of mechanical trituration before it is applied to the soil.

Common Salt is an ingredient of crops, but most soils supply it in abundance for the wants of the plant. Its application is only likely to be useful as a source of plant food in growing such crops as mangels, onions, cabbages, etc., which contain a considerable percentage of chloride of sodium in their ash. It is necessary only on soils naturally deficient in salt, and situated so far inland as to be beyond the influences of the salt-laden sea-breezes.

On grass lands salt is best used as a compost with vegetable matter; and in that form it may be given at the rate of from three hundred to five hundred pounds per acre. On arable land it is also best given as a compost. If used alone, however, the application should not exceed three hundred to five hundred pounds per acre, and it should be well harrowed in.

The destructive action of salt in excess on vegetation is turned to account sometimes in destroying weeds on garden paths, etc. It can also be taken advantage of at times as a corrective to the over-stimulating effects of nitrate of soda and other manures on wheat crops. When these are running too much to straw an application of salt may check this tendency and prevent lodging.

Soot contains a small percentage of nitrogen. Used alone it makes an excellent top-dressing for spring wheat and grass; being quick in its action without being too stimulating. It has also the property of destroying slugs on winter wheat; and it keeps off other pests.

Vegetable-ashes.—Kelp, the burnt ash of sea-weed, contains a large quantity of potash. It takes twenty-four tons of sea-weed to produce one ton of kelp.

Wood-ashes are rich in potash, and constitute a valuable manure for potatoes and turnips. They are used to the best advantage when mixed with superphosphate and other manures.

Cotton-cake-dust, and Malt-dust.—The value of these substances is chiefly dependent on the large quantity of nitrogen which they contain.

Cotton-cake-dust has recently been tried with extraordinary effect on poor cotton lands. This could not be due altogether to the connection which existed between the chemical properties of the manure and those of the crop. Their value as feeding-stuffs hinders their use as manures.

Fish refuse contains nearly two per cent. of nitrogen, and one per cent. of phosphoric acid. It answers well as a manure for both wheat and root crops when made into a compost with its own weight of soil, and allowed to decompose before being applied. Fish guano is a manufacture of the refuse from oil-pressing and fish-curing establishments by pressure and treatment with sulphuric acid.

Bullock's Blood is used on a large scale as a manure, but chiefly for mixing with other fertilizers. In its natural state blood contains about three per cent. of nitrogen; when dried it contains twelve per cent. It makes an excellent manure for turnips when mixed with bone-dust or phosphatic guano; and, mixed with peat or mould, may be very advantageously applied as a top-dressing to wheat crops and to grass land.

Sea-weed is largely used as a manure on some parts of the coast. It is especially suited for the potato crop, which requires much potash—a large mineral constituent of sea-weed. Sometimes it is used as a top-dressing to grass land. The action of sea-weed is the same as a green crop plowed in. It contains all the ordinary constituents of land plants. As it putrifies rapidly, it forms a quick manure. It is applied at the rate of twenty to thirty tons per acre. The usual practice is to spread it on the soil and plow it in; but it is occasionally formed into a compost with earth and dung. The neighborhood of the coast is in some districts a distinct element in the value of the land, on account of the sea-weed as a manure, which is thus more cheaply obtained.

Sewage as a Manure.—The difficulty in the way of its use is its enormous bulk in proportion to its valuable constituents. A ton of city sewage ordinarily contains only three pounds of solid matter—viz., one pound of organic and two pounds of mineral constituents, the former yielding less than three ounces of ammonia, and the latter half an ounce of phosphoric acid and one and a half ounces of potash; so that in a ton or sewage there is only about five ounces of fertilizing matter. One ton of guano may thus contain as much of the food of plants as twelve hundred tons of sewage. According to the market price of the former the theoretical value of the sewage ought thus to be about five cents per ton. Practically, however, there is no comparison between the values of the two manures; because it is found that ten or even twenty times the theoretic equivalent of sewage is required to produce the effect of guano; and considering the far greater cost of utilizing the sewage, only a nominal price can be put upon it.

There are several methods of utilizing sewage:—

Irrigation is the method which has been most largely practised. It consists in distributing the sewage over the surface of well-drained fields, from reservoirs into which the sewers empty, or into which their contents are pumped.

In the dry-earth system the sewage nuisance is dealt with house by house. Dry pulverized earth in movable boxes in privies is made the receptacle in which excreta are covered and rendered harmless, being still serviceable for gardens and fields. The system, fit enough for institutions where discipline prevails, is hardly applicable to large towns, where it would entail the bringing in dry earth to the amount of from five to ten pounds for each individual daily.

The Liquid Manure of the Farm is the drainings or the washings from the farm-yard manure. The best use that can be made of it probably is to return it to the dung heap, where means should be devised for its absorption or retention. If allowed to flow away from the cattle sheds or from the manure pile, it should be collected in tanks. From the collecting tanks it may be distributed over the land by a watering-cart, when the area is small. On a larger scale, pipes are laid underground in the field, and the manure distributed either by gravitation or by pumping. The gravitation system is the only practicable one on the score of expense. Liquid manure is chiefly valuable for the rapidity with which it produces its effect. It is well adapted to light sandy soils, but a failure on heavy clays. It is also more suitable for grass and root crops than for grain crops. By its use grass may be cut six or eight times in the course of a year.

Application of Manures.—The tendency of modern practice in manuring is to use readily soluble and quick-acting manures, but to use them sparingly at a time. Little and often is the rule.

In applying fertilizers of a soluble character, it is found economical to manure the plant rather than the soil. The practice is especially applicable to mangels, cabbages, and other drilled crops, where the plants are a considerable distance apart in the rows. The manure is deposited by the drill along the line of each plant row, and immediately covered in. Manures which are not so readily soluble produce the best effect when intimately mixed with the soil. The depth to which the manure is turned in should be regulated by the nature of the soil and of the manure. On a clay soil it may be buried deeper with advantage than on a sandy soil; and a slow manure may be buried deeper than a soluble and quick-acting manure. It is not, however, good policy to bury any manure very deeply. The rain in a drained soil will soon distribute it throughout the mass to be fertilized; but we must not forget that the producing power of a soil is governed more by the mass of its vegetable bed than by the measure of its superficies; and where the subsoil is unmanured the crop will often be underfed. One of the causes of the failure of red clover is traced, we believe, to the dying off of the roots when they penetrate beyond the depth of available manure. Soluble manures, like nitrate of soda and sulphate of ammonia, should be put on the surface; but undissolved phosphate, and even guano, is best when just covered with the soil. Stiff clays are immensely benefited by a good dressing of fresh farm-yard manure plowed under to a tolerable depth.

Top-dressings with artificial manures are chiefly to be recommended for crops in the grassy stages of their growth—wheat crops in spring, and grass lands at the same season, and especially in wet seasons. In such seasons one objection to this method of applying manure to wheat is the tendency which it produces in the crop to lodge. Salt will partly counteract this effect, and it does so by strengthening and to some extent shortening the straw; but this is to counteract one of the principal objects of top-dressing. On clay soils, which produce strong straw, the tendency to lodge is less than on lighter soils. In dry seasons, on the other hand, top-dressings of artificial manures are often inefficient, and the drier the climate the less likely are they to answer. But there are doubtless circumstances when top-dressing may be profitable in any season—as on poor soils, and where the manure is applied for the first time on newly reclaimed land. A top-dressing of farm-yard manure always produces a good effect. In a wet season it is washed into the soil. In a dry one it is often very efficacious as a mulch on grass and arable land, too, if, as is sometimes done, it be applied to the latter immediately after the crop is put in, and before the plants come up.

Artificial manures may be applied either in a dry or liquid form, broadcast, or in the drill. The common practice for root crops, beans, and peas, at least, is to deposit in the drills either by hand or machine; but for potatoes, where roots are grown on the ridge, the manure is frequently distributed broadcast, previous to forming the drills, when it becomes more mixed with the soil. There are now manure distributers in use for this purpose; and they are equally suitable for applying top-dressings of light manures.

Great advantage has attended the use of the water-drill for sowing turnip and mangel seed in dry seasons. By applying the manure in a liquid state, the germination of the seed and the subsequent brairding can generally be relied on. In a dry climate, the water-drill is desirable in any year, if root crops, which have to be put in at the driest and hottest season, are to be successfully cultivated. The same quantity of manure is used as in the dry state, and the quantity of water is regulated by the condition of the land and the dryness of the atmosphere. Superphosphate and guano are the most suitable manures for the water-drill.

The need of providing for the self-maintenance of a soil by good management of the home resources is hardly of the urgency that it once possessed, now that we have helps in auxiliary manures, formerly unknown, at our command, but in economical agriculture the question will always be important; and the alternative of maintaining fertility by the purchase of auxiliary manures (producing their whole effect almost at once) or by purchases of food for live stock and the artificial enrichment of their manure, will always be one of the most interesting for the farmer. The latter plan, which now forms part of all good farm management, is theoretically much the more economical, and practically much the more enduring.

Considering the operations of animal nutrition and growth as a mere chemical process, the manure excreted has a value which, calculated according to the data supplied by the manure market, is a very large proportion of the original market price of the food. Sir John B. Lawes has prepared the following table, giving the value which ought to be realized from the manure derived from different kinds of food:

Description of Food.	*Money value of the Manure from one ton of each food.*	*Description of Food.*	*Money value of the Manure from one ton of each food.*
Decorticated cotton seed cake	$32.50	Barley	$ 7.50
Rape cake	24.62	Clover hay	11.37
Linseed cake	23.12	Meadow hay	7.62
Common cotton-seed cake	19.62	Bean straw	5.12
Beans	18.50	Pea straw	4.68
Linseed	18.25	Oat straw	3.37
Peas	15.62	Wheat straw	3.12
Indian meal	7.75	Barley straw	2.68
Malt dust	21.37	Potatoes	1.75
Bran	14.50	Parsnips	1.37
Oats	8.75	Mangel wurzel	1.31
Wheat	8.25	Swedish turnips	1.06
Malt	7.75	Common turnips	1.00
		Carrots	1.00

These are the estimated values of the food remnants in the several cases named, calculated upon the market prices of the several fertilizing ingredients which they contain; and if there were no waste anywhere in the management of the manure before it reaches the soil, or in the soil itself before it reaches the plant, these figures might be realized. At present, they do but give the possible result of an unattainable economy, and they can only be kept before us as a goal at which to aim rather than as one which we may expect to reach

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CHAPTER IX.

THE LOSS OF NITROGEN.*

The Loss of Nitrogen in purchased manures; The loss of Nitrogen as Nitric Acid.

BY J. B. LAWES, LL.D., F. R. S.

On the Loss of Nitrogen in Purchased Manures when Applied to Crops.—There is one great advantage that writers on the subject of Agriculture in the United States possess over the same class in Great Britian; they are sure to obtain an impartial hearing. In the United States a farmer, on coming across any views, or statements on the subject of agriculture that are new to him, asks himself the question, are these true; and, if so, what benefit can I derive from them? In Great Britain, from the conflicting interests of the owner of the land, and the occupier who pays an annual rent for the right to cultivate it, the teachings of science are likely to be praised or blamed accordingly as they affect the interests

*Nitrogen is one of the most important constituents of barn-yard and of artificial fertilizers. When purchased it is the most costly element in fertilizers, and whatever relates to its loss, and incidentally to its preservation, is of great importance to the farmer. In view of this, the accounts in this chapter of some experiments at Rothamsted, England, written for the "American Agriculturist" by Sir J. B. Lawes, will be read with special interest.

of the owner rather than those of the cultivator of the soil. A few years ago, when public attention was directed to the vast increase in the amount of agricultural produce sent from the States to England, there were many who put forward the view that, by a more liberal application of capital to the soil, we could grow all the wheat required to feed our population. Under these circumstances I thought it my duty to caution tenant farmers against paying too much attention to statements which were uttered by those who had no experience in either practical or scientific agriculture. I accordingly delivered a lecture before a farmer's club, in which I endeavored to show, by the teaching of my own experiments, that a higher system of farming was not so certain a remedy for falling prices as some wished them to believe.

In a letter recently published in a paper devoted to field sports, which I have been informed is much read by the owners of land, a writer who signs himself "Agricola," makes the following observations: "Certain pamphlets of Mr. Lawes have done intolerable mischief in giving a false coloring to the service higher farming might render in enabling British farmers to tide over the present crisis," and he goes on to say that we have the counterblasts of M. Georges Ville to send all unsubstantial utterances beyond the domain of rational consideration!

If in speaking of the immense influence which such nitrogenous manures as ammonia, or nitric acid, produce upon the growth of our ordinary cereal crops, I had pointed out that, owing to the high price of these substances, it was by no means certain the increase in produce would pay for their application; and consequently it would be desirable for the United States farmer to exercise some caution in their use. I think it is hardly possible to believe, that any one in the States could suppose such a caution would be productive of evil.

In another case I was rather amused at a correspondence which I lately noticed between M. Georges Ville and some one who had called his attention to my views with regard to the sources of the nitrogen in vegetation, which were altogether antagonistic to those entertained by M. Ville. M. Ville, in his answer, stated that he had heard of the existence of a pamphlet on the subject, but that he was so much engaged in showing how foreign competition could be best overcome, that he had not time to look into it, but that he would do so, in order to see whether it would be necessary for him to answer it himself, or whether he should leave the task to one of his pupils.

With regard to the subject of nitrogen, the views I am disposed to entertain may be briefly summarized as follows:—(1) That the soil and not the atmosphere is the main source of the nitrogen which we find in our crops. (2) That in the application of manures containing nitrogen, more or less loss of that substance is always incurred; and consequently, if the object is to obtain any given amount of nitrogen in the produce, the application in the form of manure must be largely in excess of the amount required. In everything relating to the competition between Europe and the United States; between the vast stores of untouched fertility of the one, and the comparatively exhausted stock of the other, the question of nitrogen is one of paramount importance. I am not aware myself of any writer, practical or scientific, who has accepted as a fact, or even entertained the idea that, in the application of nitrogen in purchased manures a considerable loss is incurred. This loss in a substance of so costly a nature is a matter of great economic importance. The view generally held, I believe, is that no loss takes place, and further, that by a small application of nitrogen, a farmer not only recovers in the crop all that he has applied in the manure, but a good deal more. This, according to M. Ville, is the economic function of our root crops, which, when well supplied with minerals, and a small amount of ammonia, get what more they require of this element from the atmosphere. The following are the views of this writer with regard to a rotation: "That some crops demand all the nitrogen they require to be supplied to them; others require a small amount, which enables them to obtain a good deal in addition from the atmosphere; while others again can obtain the whole of the nitrogen they need from the atmosphere." This explanation appears so simple and clear that it seems quite a pity to say anything that could throw a doubt upon its accuracy.

I will now endeavor to show what loss of the nitrogen in the manure has taken place in our own experiments on the growth of potatoes at Rothamsted. In order to measure the effect of nitrogen, and also ascertain whether any, and if so what amount of loss has taken place, our plan has been to grow the crop continuously, with mineral manures alone. We consider that by this means the crop avails itself of all the sources of nitrogen at its disposal, whether they be derived from the soil or the atmosphere. When, in addition to the same minerals, nitrogen in some soluble form is applied to the potatoes in another experiment, we consider that the increase in the crop over that grown by minerals alone, is due to the nitrogen of the manure; and further, if we deduct the amount of nitrogen in the crop grown by minerals alone, from the amount contained in the crop grown by minerals and nitrogen, the residue, when compared with the amount of nitrogen applied in the manure, will give us the measure of the loss. I must observe, however, that this experiment requires to be continued for a good many years before any safe conclusions can be drawn; first, because of the great influence of favorable or unfavorable seasons; and, secondly, because it is only by the aid of time that we can ascertain whether the nitrogen applied, but not recovered in one crop, is available for those which succeed. The more favorable is the season for the growth of a crop, the better will the crop be able to avail itself of the stores of manure furnished by the soil and atmosphere. At Rothamsted, the season of 1881 was very favorable for the growth of potatoes; I therefore select that year's crop, not as indicating what might be the average loss of nitrogen applied in manure, but to show how very serious may be the loss, even under exceptionally favorable conditions. The following table gives the number of bushels of potatoes of fifty pounds each:

TABLE.

	Bushels per Acre.
(1) Potash, soda, magnesia, superphosphate	265
(2) The same as (1) with 400 lbs. salts of ammonia	484
Gain by addition of ammonia	219

It is quite evident that the mineral manures enabled the potatoes to gather up a large amount of nitrogen; and that further growth was only arrested for want of more nitrogen, is evident by the much larger crop grown when a manure containing that substance was used; this fact is still further confirmed by the analyses of the potatoes grown by mineral manures alone, which show a very low percentage of nitrogen. Assuming that the ordinary potatoes in a dry state contain one per cent. of nitrogen, these potatoes contained one-sixth less than that amount, and it is probable that under such conditions no further growth was possible.

We now come to the loss of nitrogen. The four hundred pounds of sulphate and muriate of ammonia are estimated to furnish about eighty-five pounds of nitrogen. Taking the potatoes grown by mineral manures alone at twenty-six pounds, we find in those grown by ammonia and minerals sixty-six pounds, or an increase of forty pounds; but as we supplied eighty-five pounds in the manure, we have recovered something less than fifty per cent. of the amount supplied, and this, too, under the influence of an unusually favorable season! Taking an average of seasons, it would be much nearer the truth to say that not more than one-third of the nitrogen supplied is recovered in the crop. Potatoes contain twenty-five per cent. of dry matter in every one hundred pounds; if we take a bushel to weigh fifty pounds, eight bushels will weigh four hundred pounds; which amount is equivalent to one hundred pounds of dry matter, and will contain one pound of nitrogen.

To obtain this one pound of nitrogen in the produce, we find it necessary to apply three pounds in the manure, and as the nitrogen costs about twenty-five cents per pound, this large difference between the amount supplied and that recovered becomes a very serious consideration.

I might further observe that as our experiments are conducted with more care and attention than could possibly be given to crops grown under the ordinary operations of agriculture, I do not think it would be safe to reckon on a smaller loss than that which we have incurred, and the probability is that it might be much larger.

The general conclusion to be drawn from these experiments, as well as from those upon root crops in general, such as turnips, mangels, and sugar beets, is that they do not obtain their nitrogen from the atmosphere; and that, when supplied with that substance, the amount recovered in the crop is very much less than that supplied in the manure.

The Loss of Nitrogen as Nitric Acid.—In one of the arable fields at Rothamsted we placed, ten years ago, three gauges, each having an area of one one-thousandth of an acre, at the various depths of twenty, forty, and sixty inches below the surface. The operation was performed without any disturbance of the soil, and no vegetation is allowed to grow upon the area occupied by the drain gauges themselves. Close to them is a rain gauge of a similar size. We obtain by this arrangement a knowledge of the rain-fall, and also of the amount of rain water which passes through the soil at different depths. From time to time analyses have been made of the water passing through the soil, and latterly the whole of the nitric acid and chlorine which the water contained has been determined. The results are in course of publication. I do not propose, therefore, on the present occasion, to do more than point out the important bearing these investigations have upon practical agriculture.

The whole history of nitric acid, as regards its bearing upon vegetation, is of quite recent date. The time is within my own recollection when it was a question of doubt whether the effect of nitrate of soda on vegetation was due to the nitrogen or the soda. At the present time it may be said that every farmer has an interest in nitric acid, and that a correct knowledge of its properties and action, with relation to our soil and crops, must be the basis of all agricultural science.

The amount of nitrogen which passes through the Rothamsted drain gauges every year since they were established, if calculated upon an acre of land, would exceed forty pounds in weight. I have made an estimate of the nitrogen contained in crops grown in the United States, taking as my basis the average produce over the whole country for ten years, and the amount removed per acre would be very much less than this. Upon ordinary arable land, therefore, which is not particularly fertile, and has remained uncropped and at rest, more nitrogen passes each year through the soil than we should find in an ordinary crop of grain, potatoes, or hay, grown in the States. Let us add to this fact three others. (1.)

That the water passing through these gauges is much richer in nitrogen than the rain which falls upon them. (2.) That it is richer in nitrogen in the autumn than at any other time of the year. (3.) That the drainage water collected in another field, where a crop of wheat was in luxurious growth, contained no nitric acid at all, and we have before us a basis from which some very important conclusions can be drawn.

We learn that the most important ingredient of the food of all plants, as also the most expensive when used artificially, is continually produced in our soils, is continually moving about, continually being taken up by vegetation, and continually being washed away and lost. Such being the case, it follows as a necessary consequence that the amount of nitrogen that analysis has proved to be contained in our crops is not a correct measure of the exhaustion of this substance, but we must add to it the amount of nitric acid which is lost from the crop being unable to take it up from one cause or another. I will endeavor to explain my meaning by an illustration taken from an ordinary operation in farming. A farmer sows two fields, one with wheat only, one with wheat and timothy, clover, rye-grass, or an assortment of these plants. The wheat is sown before the seeds, and takes the largest share of the light and food; soon after blooming the wheat ceases to gather food from the soil, and in the early summer, the crop being ripe, is carried away. The seeds are thus relieved from a powerful antagonist, and, having complete possession of the soil, continue to grow both above and below it until they are stopped by frost; even then it is probable that the roots, which are beneath the region of frost, grow and collect food.

Assuming the wheat field not sown with grass to be without weeds at the time of harvest, and afterwards (a very improbable assumption, I admit,) it would resemble the soil of my drain gauges, and be subject to the same losses from the washing out of the nitric acid by the winter rains. A high temperature is favorable to the production of nitric acid in our soil, and the collecting power of the wheat has ceased before the highest temperature of the summer has been reached. We may make an imaginary sum of the result as follows:

	Lbs. of nitrogen washed away per acre.
From soil without vegetation	40
From soil with wheat, 15 lbs. retained by crop	25
From soil with wheat aud seeds—retained by wheat, 15 lbs.; by seeds, 25 lbs	5

Green vegetation is the great agent by which nitric acid is converted into insoluble forms; it is evident, therefore, that before we can assign to any of our crops their proper economic function in a rotation, we must take into account both the length of time to which the period of their growth extends, and also the range and depth of their roots. The tendency of the Rothamsted experiments is every year leading us more and more to the conclusion, that the source of nitrogen in our crops is to be found in the amount of that substance stored up in our soils. If further investigation should establish this to be absolutely true, the current ideas with regard to the properties of several of our crops will require considerable modification.