LECTURES
ON
AGRICULTURAL CHEMISTRY AND GEOLOGY:

TO WHICH ARE ADDED,

SUGGESTIONS FOR EXPERIMENTS IN PRACTICAL AGRICULTURE.

BY

JAS. F. W. JOHNSTON, M.A., F.R.SS. L. & E.

Fellow of the Geological Society, Honorary Member of the Royal Agricultural Society, &c. &c.; Reader in Chemistry and Mineralogy in the University of Durham, &c.

These Lectures will be divided into four Parts, of which the First is now ready; the others are in course of publication, and the whole will be completed in two volumes.

OUTLINE OF PART I.—"*On the Organic Constituents of Plants.*"—Lecture I. Elementary substances of which plants subsist. II. and III. Compound substances which minister to the growth of plants. IV. Sources from which plants immediately derive their elementary constituents. V. How the food enters into the circulation of plants—general structure of plants. VI. Into what substances the food is changed in the interior of plants—substances of which plants chiefly consist. VII. Chemical changes by which the substances of which plants chiefly consist are formed from those on which they live. VIII. How the supply of food for plants is kept up in the general vegetation of the globe.

OUTLINE OF PART II.—"*On the Inorganic Constituents of Plants—the Origin, Classification, and Chemical Constitution of Soils—General and Special Relations of Geology to Agriculture—Origin, Constitution, Analyses, and Methods of Improving Soils in different Districts and under unlike conditions.*"—Lecture IX. Kind and proportion of inorganic matter contained in plants. X. Properties of the inorganic compounds which exist in vegetable substances, or which promote their growth. XI. Of the nature, origin, and classification of soils—Structure of the earth's crust—Classification and general characters of the stratified rocks—Agricultural capabilities of the soils derived from them. XII. Granite and trap rocks, and the soils derived from them—Superficial accumulations. XIII. On the exact chemical constitution, the analysis, and the physical properties of soils.

Part III.—Methods of improving the soil by mechanical and by chemical means—Manures, their nature, composition, and mode of action—theory of their application in different localities.

Part IV.—The results of vegetation—the nature, constitution, and nutritive properties of different kinds of produce, and by different modes of cultivation—the feeding of cattle, the making of cheese, &c. &c. The constitution and differences of various kinds of wood, and the circumstances which favour their growth.

CRITICAL NOTICES.

"A valuable and interesting course of lectures."—*Quarterly Review.*

"But it is unnecessary to make large extracts from a book which we hope and trust will soon be in the hands of nearly all our readers. Considering it as unquestionably the most important contribution that has recently been made to popular science, and as destined to exert an extensively beneficial influence in this country, we shall not fail to notice the forthcoming portions as soon as they appear from the press."—*Silliman's American Journal of Science. Notice of Part I. of the American reprint.*

"We think it no compliment to Professor Johnston to say, that among our own writers of the present day who have recently been endeavouring to improve our agriculture by the aid of science, there is probably no other who has been more eminently successful, or whose efforts have been more highly appreciated."—*County Herald.*

"Prof. Johnston is one who has himself done so much already for English agriculture, that to behold him still in hot pursuit of the inquiry into what *can* be done, supplies of itself a stimulus to further exertion on the part of others."—*Berwick Warder.*

ELEMENTS

OF

AGRICULTURAL CHEMISTRY, &c.

ELEMENTS

OF

AGRICULTURAL

CHEMISTRY AND GEOLOGY.

BY

JAS. F. W. JOHNSTON, M.A., F.R.S.,

HONORARY MEMBER OF THE ROYAL ENGLISH AGRICULTURAL SOCIETY, AND AUTHOR OF "LECTURES ON AGRICULTURAL CHEMISTRY AND GEOLOGY."

NEW-YORK:

WILEY AND PUTNAM.

MDCCCXLII.

J. P. Wright, Printer,
18 New Street, N. Y.

INTRODUCTION.

THE scientific principles upon which the art of culture depends, have not hitherto been sufficiently understood or appreciated by practical men. Into the causes of this I shall not here inquire. I may remark, however, that if AGRICULTURE is ever to be brought to that comparative state of perfection to which many other arts have already attained, it will only be by availing itself, as they have done, of the many aids which Science offers to it; and that, if the practical man is ever to realize upon his farm all the advantages which Science is capable of placing within his reach, it will only be when he has become so far acquainted with the connection that exists between the art by which he lives and the sciences, especially of Chemistry and Geology, as to be prepared to listen with candour to the suggestions they are ready to make to him, and to attach their proper value to the explanations of his various processes which they are capable of affording.

The following little Treatise is intended to present a familiar outline of the subjects of *Agricultural Chemistry and Geology*, as treated of more at large in my LECTURES, of which the first Part is now before the public. What in this work has necessarily been taken for granted, or briefly noticed, is in the LECTURES examined, discussed, or more fully detailed.

Durham, 8th April, 1842.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

ELEMENTS

OF

AGRICULTURAL CHEMISTRY, &c.

CHAPTER I.

Distinction between Organic and Inorganic Substances.—The Ash of Plants—Constitution of the Organic Parts of Plants.—Preparation and Properties of Carbon, Hydrogen, and Nitrogen.—Meaning of Chemical Combination.

The object of the practical farmer is to raise from a given extent of land the largest quantity of the most valuable produce at the least cost, and with the least permanent injury to the soil. The sciences either of chemistry or geology throw light on every step he takes or ought to take, in order to effect this main object.

SECTION I.—OF THE VEGETABLE AND EARTHY OR THE ORGANIC AND INORGANIC PARTS OF PLANTS.

In the prosecution of his art, two distinct classes of substances engage his attention—the *living* crops he raises, and the *dead* earth from which they are gathered. If he examine any fragment of an animal or vegetable, either living or dead, he will observe that it exhibits pores of various kinds arranged in a certain order—that it has a species of internal structure—that it has various parts or *organs*—in short, that it is what physiologists term *organized*. If he examine, in like manner, a lump of earth or rock, he will perceive no such structure. To mark this distinction, the parts of animals and vegetables, either living or dead—whether entire or in a state of decay, are called *organic* bodies, while earthy and stony substances are called *inorganic* bodies.

Organic substances are also more or less readily burned and dissipated by heat in the open air; inorganic substances are generally fixed and permanent in the fire.

But the crops which grow upon it, and the soil in which they are rooted, contain a portion of both of these classes of substances. In all fertile soils, there exists from 3 to 10 per cent. of vegetable or other matter of *organic* origin ; while, on the other hand, all vegetables, as they are collected for food, leave, when burned, from one-half to twenty per cent. of *inorganic* ash.

If we heat a portion of soil to redness in the open air, the organic matter will burn away, and, in general, the soil, if previously *dry*, will not be materially diminished in bulk. But if a handful of wheat, or of wheat straw, or of hay, be burned in the same manner, the proportion that disappears is so great, that in most cases a comparatively minute quantity only remains behind. Every one is familiar with this fact who has seen the small bulk of ash that is left when weeds, or thorns, or trees, are burned in the field, or when a hay or corn-stack is accidentally consumed. Yet the ash thus left is a very appreciable quantity, and the study of its true nature throws much light, as we shall hereafter see, on the practical management of the land on which any given crop is to be made to grow.

Thus the quantity of ash left by a ton of wheat straw is sometimes as much as 360 lbs.; by a ton of oat straw as much as 200 lbs.; while a ton of the grain of wheat leaves only about 40 lbs.; of the grain of oats about 90 lbs.; and of oak wood only

4 or 5 lbs. The quantities of *inorganic* matter, therefore, though comparatively small, yet, in some cases, amount to a considerable weight in an entire crop. The nature, source and uses of this earthy matter will be explained in a subsequent chapter.

SECTION II.—CONSTITUTION OF THE ORGANIC PART OF PLANTS AND ANIMALS.

The organic part of plants, when in a perfectly dry state, constitutes therefore from 85 to 99 per cent. of their whole weight. Of those parts of plants which are cultivated for food, it is only hay and straw, and a very few others, that contain as much as 10 per cent. of inorganic matter.

This organic part consists of four substances, known to chemists by the names of carbon, hydrogen, oxygen, and nitrogen. The first of these, carbon, is a solid substance, the other three are gases or peculiar kinds of air.

1. Carbon. When wood is burned in a covered heap, as is done by the charcoal burners, or is distilled in iron retorts, as in making wood-vinegar, it is charred and converted into common wood charcoal. This charcoal is the most usual and best known variety of carbon. It is black, soils the fingers, and is more or less porous

according to the kind of wood from which it has been formed. Coke obtained by charring or distilling coal is another variety. It is generally denser or heavier than the former, though less pure. Black lead is a third variety, still heavier and more impure. The diamond is the only form in which carbon occurs in nature in a state of perfect purity.

This latter fact, that the diamond is pure carbon—that it is essentially the same substance with the finest and purest lamp-black—is very remarkable ; but it is only one of many striking circumstances that every now and then present themselves before the inquiring chemist.

Charcoal, the diamond, lamp-black, and all the other forms of carbon, burn away more or less slowly when heated in the air, and are converted into a kind of gas known by the name of *carbonic acid.* The impure varieties leave behind them a greater or less proportion of ash.

2. Hydrogen.—If oil of vitriol (sulphuric acid) be mixed with twice its bulk of water, and then poured upon iron filings, the mixture will speedily begin to boil up, and bubbles of gas will rise to the surface of the liquid in great abundance. These are bubbles of hydrogen gas.

If the experiment be performed in a bottle, the hydrogen which is produced will gradually drive out the atmospheric air it contained, and will itself take its place. If a bit of wax taper be tied to the end of a wire, and when lighted be introduced into the bottle, it will be instantly extinguished; while the hydrogen will take fire, and burn at the mouth of the bottle with a pale yellow flame. If the taper be inserted before the common air is all expelled, the mixture of hydrogen and common air will burn with an explosion more or less violent, and may even shatter the bottle and produce serious accidents. This experiment, therefore, ought to be made with care. It may be safely made in an open tumbler, covered by a plate or a piece of paper, till a sufficient quantity of hydrogen is collected, when, on the introduction of the taper, the light will be extinguished, and the hydrogen will burn with a less violent explosion.

This gas is also an exceedingly light substance, rising through common air as wood does through water. Hence, when confined in a bag made of silk, or other light tissue, it is capable of sustaining heavy substances in the air, and even of transporting them to great heights. For this reason it is employed for filling and elevating balloons.

Hydrogen gas is not known to occur anywhere in nature in any sensible quantity. It is very abundant, as we shall hereafter see, in what by chemists is called a *state of combination.*

3. Oxygen.—When strong oil of vitriol is poured upon black oxide of manganese, and heated in a glass retort: or when red oxide of mercury, or chlorate of potash, is so heated alone; or when saltpetre, or the same oxide of manganese, is heated alone in an iron bottle;—in all these cases a kind of air is given off, which, when collected and examined by plunging a taper into it, is found to be neither common air nor hydrogen gas. The taper, when introduced, burns with great rapidity, and with exceeding brilliancy, and continues to burn till either the whole of the gas disappears, or the taper is entirely consumed. If a living animal is introduced, its circulation and its breathing become quicker—it is speedily thrown into a fever—it lives as fast as the taper burned—and, after a few hours, dies from excitement and exhaustion. This gas is not light like hydrogen, but is about one-ninth part heavier than common air.

In the atmosphere, oxygen exists in the state of gas. It forms about one-fifth of the bulk of the air we breathe, and is the substance which, in the air, supports all animal life and the combustion of all burning bodies. Were it by any cause suddenly removed from the atmosphere of our globe, every living thing would perish, and all combustion would become impossible.

4. Nitrogen.—If a saucer be half filled with milk of lime, formed by mixing slaked quicklime with water, a *very* small tea-cup containing a little burning sulphur then placed in the middle, and a common large tumbler inverted over the whole, the sulphur will burn for a while, and will then gradually die out. On allowing the whole to remain for some time, the fumes of the sulphur will be absorbed by the milk of lime, which will rise a certain way into the tumbler. When the absorption has ceased, a quantity of air will remain in the upper part of the tumbler. This air is nitrogen gas.

If the whole be now introduced into a large basin of water, the tumbler being held in the left hand, the cup and saucer may be removed from beneath. The saucer may then be inverted and introduced with its under side into the mouth of the tumbler, which may thus be lifted out of the water and restored to its upright position, the saucer serving the purpose of a cover. By carefully removing this cover with the one hand, a lighted taper may be introduced by the other. It will then be seen that the taper is extinguished by this air, and that no other effect follows. Or if a living animal be introduced into it, breathing will instantly cease, and it will drop without signs of life.

This gas possesses no other remarkable property. It is a very little lighter than common air, and is known to exist in large quantity in the atmosphere only. Of the air we breathe it forms nearly four-fifths of the entire bulk.

These three gases are incapable of being distinguished from common air, or from each other, by the ordinary senses; but by the aid of the taper they are readily recognised. Hydrogen extinguishes the taper, but itself takes fire; nitrogen simply extinguishes it; while in oxygen the taper burns with extraordinary brilliancy and rapidity.

Of this one solid substance, carbon, and these three gases, hydrogen, oxygen, and nitrogen, all the organic part of vegetable and animal substances is made up.

Into these substances, however, they enter in very different proportions. Nearly one half the weight of all vegetable productions which are gathered as food for man or beast—in their dry state—consists of carbon; the oxygen amounts to rather more than one third, the hydrogen to little more than five per cent., while the nitrogen rarely exceeds two and a half or three per cent. of their weight.

This will appear from the following table, which exhibits the actual constitution by analysis of some varieties of the more common crops when perfectly dry.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Hay, ...	458	50	387	15	90
Potatoes, . .	441	58	439	12	50
Wheat Straw, .	485	52	389½	3½	70
Oats, ...	507	64	367	22	40

These numbers represent the weights of each element in pounds, contained in 1000 lbs. of the dry hay, potatoes, &c.; but in drying by a gentle heat, 1000 lbs. of hay from the stack, lost 158 lbs. of water, of potatoes wiped dry externally 722 lbs.,* wheat straw 260 lbs., and oats 151 lbs.

SECTION III.—OF THE MEANING OF CHEMICAL COMBINATION.

If the three kinds of air above spoken of be mixed together in a bottle, no change will take place, and if charcoal in fine powder be added to

* Both potatoes and turnips contain about four-fifths of their weight of water, or five tons of either of these roots contain nearly four tons of water.

them, still no new substance will be produced. If we take the ash left by a known weight of hay or wheat straw, and mix it with the proper quantities of the four elementary substances, carbon, hydrogen, &c., as shewn in the above table, we shall be unable by this means to form either hay or wheat straw. The elements of which vegetable substances consist, therefore, are not merely *mixed* together—they are united in some closer and more intimate manner. To this more intimate state of union, the term *chemical combination* is applied—the elements are said to be *chemically combined.*

Thus, when charcoal is burned in the air, it slowly disappears, and forms, as already stated, a kind of air known by the name of carbonic acid gas, which rises into the atmosphere and disappears. Now, this carbonic acid is formed by the *union* of the carbon (charcoal), while burning, with the oxygen of the atmosphere, and in this new air the two elements, carbon and oxygen, are *chemically combined.*

Again, if a piece of wood or a bit of straw, in which the elements are already chemically combined, be burned in the air, these elements are separated and made to assume new states of combination, in which new states they escape into the air and become invisible. When a substance is thus changed by the action of heat, it is said to be *decomposed*, or if it gradually decay and perish by exposure to the air and moisture, it undergoes slow *decomposition.*

When, therefore, two or more substances unite together, so as to form a third possessing properties different from both, they enter into chemical union —they form a *chemical combination* or chemical *compound.* When, on the other hand, one compound body is so changed as to be converted into two or more substances different from itself, it is *decomposed.* Carbon, hydrogen, &c., are chemically combined in the interior of the plant during the formation of wood: wood, again, is decomposed when by the vinegar-maker it is converted among other substances into charcoal and wood-vinegar, and the flour of grain when the brewer or distiller converts it into ardent spirits.

CHAPTER II.

Form in which these different substances enter into Plants. Properties of the Carbonic, Humic, and Ulmic Acids—of Water, of Ammonia, and of Nitric Acid. Constitution of the Atmosphere.

SECTION I. FORM IN WHICH THE CARBON, ETC. ENTER INTO PLANTS.

It is from their food that plants derive the carbon, hydrogen, oxygen, and nitrogen, of which their organic part consists. This food enters partly by the minute pores of their roots, and partly by those which exist in the green part of the leaf and of the young twig. The roots bring up food from the soil, the leaves take it in directly from the air.

Now, as the pores in the roots and leaves are very minute, carbon (charcoal) cannot enter into either in a *solid* state; and as it does not dissolve in water, it cannot, in the state of simple carbon, be any part of the food of plants. Again, hydrogen gas neither exists in the air nor usually in the soil—so that, although hydrogen is always found in the substance of plants, it does not enter them in the state of the gas above described. Oxygen exists in the air, and is directly absorbed both by the leaves and by the roots of plants; while nitrogen, though it forms a large part of the atmosphere, is not supposed to enter *directly* into plants in any considerable quantity.

The whole of the carbon and hydrogen, and the greater part of the oxygen and nitrogen also, enter into plants in a state of *chemical combination* with other substances; the carbon chiefly in the state of *carbonic acid*, and of certain other soluble compounds which exist in the soil; the hydrogen and oxygen in the form of water: and the nitrogen in those of ammonia or nitric acid. It will be necessary therefore briefly to describe these several compounds.

SECTION II.—OF THE CARBONIC, HUMIC, AND ULMIC ACIDS.

1. CARBONIC ACID.—If a few pieces of chalk or limestone be put into the bottom of a tumbler, and a little spirit of salt (muriatic acid) be poured upon

them, a boiling up or *effervescence* will take place, and a gas will be given off, which will gradually collect and fill the tumbler; and when produced very rapidly, may even be seen to run over its edges. This gas is carbonic acid. It cannot be distinguished from common air by the eye; but if a taper be plunged into it, the flame will immediately be extinguished, while the gas remains unchanged. This kind of air is so heavy, that it may be poured from one vessel into another, and its presence recognised by the taper. It has also a peculiar odour, and is exceedingly suffocating, so that if a living animal be introduced into it, life immediately ceases. It is absorbed by water, a pint of water absorbing or dissolving a pint of the gas.

Carbonic acid exists in the atmosphere; it is given off from the lungs of all living animals while they breathe; it is also produced largely during the burning of wood, coal, and all other combustible bodies, so that an unceasing supply of this gas is poured into the air. Decaying animal and vegetable substances also give off this gas, and hence it is always present in greater or less abundance in the soil, and especially in such soils as are rich in vegetable matter. During the fermentation of malt liquors, or of the expressed juices of different fruits,

—the apple, the pear, the grape, the gooseberry—it is produced, and the briskness of such fermented liquors is due to the escape of this gas. From the dung and compost heap it is also given off; and when put into the ground in a fermenting state, farm-yard manure affords a rich supply of carbonic acid to the young plant.

Carbonic acid consists of carbon and oxygen only, combined together in the proportion of 28 of the former to 72 of the latter, or 100 lbs. of carbonic acid contain 28 lbs. of carbon and 72 lbs of oxygen.

2. HUMIC AND ULMIC ACIDS.—The soil always contains a portion of vegetable matter (called *humus* by some writers), and such matter is always added to it when it is manured from the farm-yard or the compost heap. During the decay of this vegetable matter, carbonic acid, as above stated, is given off in large quantity, but other substances are also formed at the same time. Among these are the two to which the names of humic and ulmic acids are respectively given. They both contain much carbon, are both capable of entering the roots of plants, and both, no doubt, in favourable circumstances, help to feed the plant.

If the common soda of the shops be dissolved in water, and a portion of a rich vegetable soil, or a bit of peat, be put into this solution, and the whole boiled, a brown liquid is obtained. If to this brown liquid, spirit of salt (muriatic acid) be added till it is sour to the taste, a brown flocky powder falls to the bottom. This brown substance is *humic* acid. But if in this process we use spirit of hartshorn (liquid ammonia), instead of the soda, *ulmic* acid is obtained.

These acids exist along with other substances in the rich brown liquor of the farm-yard, which is so often allowed to run to waste; they are also produced in greater or less quantity during the decay of the manure after it is mixed with the soil, and no doubt yield to the plant a portion of that supply of food which it must necessarily receive from the soil.

SECTION III.—OF WATER, AMMONIA, AND NITRIC ACID.

1. Water.—If hydrogen be prepared in a bottle, in the way already described, and a gas-burner be fixed into its mouth, the hydrogen may be lighted, and will burn as it escapes into the air. Held over this flame a cold tumbler will become covered with dew, or with little drops of water. This water is *produced* during the burning of the hydrogen; and as it takes place in pure oxygen

gas as well as in the open air, this water must contain the hydrogen and oxygen which disappear, or *must consist of hydrogen and oxygen only.*

This is a very interesting fact; and were it not that chemists are now familiar with many such, it could not fail to appear truly wonderful that the two gases, oxygen and hydrogen, by their union, should form so very different a substance as water is from either. It consists of 1 of hydrogen to 8 of oxygen, or every 9 lbs. of water contain 8 lbs. of oxygen and 1 lb. of hydrogen.

Water is so familiar a substance, that it is unnecessary to dwell upon its properties. When pure, it has neither colour, taste, nor smell. At 32° of Fahrenheit's* scale (the freezing point), it solidifies into ice, and at 212° it boils, and is converted into steam. There are two others of its properties which are especially interesting in connection with the growth of plants.

1*st*, If sugar or salt be put into water, they disappear or are *dissolved*. Water has the power of thus dissolving numerous other substances in greater or less quantity. Hence, when the rain falls and sinks into the soil, it dissolves some of the soluble sub-

* This is the scale of the common thermometer used in this country.

stances it meets in its way, and rarely reaches the roots of plants in a pure state. So waters that rise up in springs are rarely pure. They always contain earthy and saline substances in solution, and these they carry with them, when they are sucked in by the roots of plants.

It has been above stated, that water absorbs (dissolves) its own bulk of carbonic acid; it dissolves also smaller quantities of the oxygen and nitrogen of the atmosphere; and hence, when it meets any of these gases in the soil, it becomes impregnated with them, and conveys them into the plant, there to serve as a portion of its food.

2d, Water is composed of oxygen and hydrogen; by certain chemical processes it can readily be resolved or decomposed *artificially* into these two gases. The same thing takes place *naturally* in the interior of the living plant. The roots absorb the water, but if in any part of the plant hydrogen be required, to make up the substance which it is the function of that part to produce, a portion of the water is decomposed and worked up, while the oxygen is set free, or converted to some other use. So, also, in any case where oxygen is required water is decomposed, the oxygen made use of, and the hydrogen liberated. Water, therefore, which abounds in the vessels of all growing plants, if not directly converted into the substance of the plant, is yet a ready and ample source from which a supply of either of the elements of which it consists may at any time be obtained.

It is a beautiful adaptation of the properties of this all-pervading compound (water), that its elements should be so fixedly bound together as rarely to separate in external nature, and yet to be at the command and easy disposal of the vital powers of the humblest order of living plants.

2. Ammonia.—If the sal-ammoniac of the shops be mixed with quicklime, a powerful odour is immediately perceived, and an invisible gas is given off which strongly affects the eyes. This gas is ammonia. Water dissolves or absorbs it in very large quantity, and this solution forms the common hartshorn of the shops. The white solid smelling-salts of the shops are a compound of ammonia with carbonic acid,—a solid formed by the union of two gases.

The gaseous ammonia consists of nitrogen and hydrogen only, in the proportion of 14 of the former to 3 of the latter, or 17 lbs. of ammonia contain 3 lbs. of hydrogen.

The chief natural source of this compound is, in the decay of animal substances. During the putrefaction of dead animal bodies ammonia is invariably given off. From the animal substances of the farm-yard it is evolved, and from all solid and liquid manures of animal origin. It is also formed in lesser quantity during the decay of vegetable substances in the soil; and in volcanic countries, it escapes from many of the hot lavas, and from the crevices in the heated rocks.

It is produced artificially by the distillation of animal substances (hoofs, horns, &c.), or of coal. Thousands of tons of the ammonia present in the ammoniacal liquors of the gas-works, which might be beneficially applied as a manure, are annually carried down by the rivers, and lost in the sea.

The ammonia which is given off during the putrefaction of animal substances rises partially into the air, and floats in the atmosphere, till it is either decomposed by natural causes, or is washed down by the rains. In our climate, cultivated plants derive a considerable portion of their nitrogen from ammonia. It is supposed to be one of the most valuable fertilizing substances contained in farm-yard manure; and as it is present in greater proportion by far in the liquid than in the solid contents of the farm-yard, there can be no doubt that much real wealth is lost, and the means of raising increased crops thrown away in the quantities of liquid manure which are almost everywhere permitted to run to waste.

3. Nitric Acid—is a powerfully corrosive liquid known in the shops by the familiar name of *aquafortis*. It is prepared by pouring oil of vitriol (sulphuric acid) upon saltpetre, and distilling the mixture. The aquafortis of the shops is a mixture of the pure acid with water.

Pure nitric acid consists of nitrogen and oxygen only; the union of these two gases, so harmless in the air, producing the burning and corrosive compound which this is known to be.

It never reaches the roots of plants in this free and corrosive state. It exists in many soils, and is naturally formed in compost heaps, and in most situations where vegetable matter is undergoing decay in contact with the air; but it is always in a state of chemical combination in these cases. With potash, it forms *nitrate of potash* (saltpetre); with soda, *nitrate of soda;* and with lime, *nitrate of lime;* and it is generally in one or other of these states of combination that it reaches the roots of plants.

Nitric acid is also naturally formed, and in some countries probably in large quantities, by the passage of electricity through the atmosphere. The air, as has been already stated, contains much oxygen and nitrogen *mixed* together, but when an electric spark is passed through a quantity of air, a certain quantity of the two *unite* together chemically, so that every spark that passes forms a small portion of nitric acid. A flash of lightning is only a large electric spark ; and hence every flash that crosses the air produces along its path a quantity of this acid. Where thunder-storms are frequent, much nitric acid must be produced in this way in the air. It is washed down by the rains, in which it has frequently been detected, and thus reaches the soil, where it produces one or other of the *nitrates* above mentioned.

It has been long observed that those parts of India are the most fertile in which saltpetre exists in the soil in the greatest abundance. Nitrate of soda, also, in this country, has been found wonderfully to promote vegetation in many localities ; and it is a matter of frequent remark, that vegetation seems to be refreshed and invigorated by the fall of a thunder-shower. There is, therefore, no reason to doubt that nitric acid is really beneficial to the general vegetation of the globe. And since vegetation is most luxuriant in those parts of the globe where thunder *or* lightning are most abundant, it would appear as if the natural production of this compound body in the air, to be afterwards brought to the earth by the rains, were a wise and beneficent contrivance by which the health and vigour of universal vegetation is intended to be promoted.

It is from this nitric acid, thus universally produced and existing, that plants appear to derive a large—probably, taking vegetation in general, the largest—portion of their nitrogen. In all climates they also derive a portion of this element from ammonia; but less from this source in tropical than in temperate climates.*

SECTION IV.—OF THE CONSTITUTION OF THE ATMOSPHERE.

The air we breathe, and from which plants also derive a portion of their nourishment, consists of a mixture of oxygen and nitrogen gases, with a minute quantity of carbonic acid, and a variable proportion of watery vapour. Every hundred gallons of dry air contain about 21 gallons of oxygen and 79 of nitrogen. The carbonic acid amounts only to one gallon in 2500, while the watery vapour in the atmosphere varies from 1 to 2½ gallons (of steam) in 100 gallons of common air.

The oxygen in the air is necessary to the respiration of animals, and to the support of combustion (burning of bodies). The nitrogen serves

* For fuller information on this point, see the Author's "LECTURES *on Agricultural Chemistry and Geology*," Part I.

principally to dilute the strength, so to speak, of the pure oxygen, in which gas, if unmixed, animals would live and combustibles burn with too great rapidity. The small quantity of carbonic acid affords an important part of their food to plants, and the watery vapour in the air aids in keeping the surfaces of animals and plants in a moist and pliant state; while, in due season, it descends also in refreshing showers, or studs the evening leaf with sparkling dew.

There is a beautiful adjustment in the constitution of the atmosphere to the nature and necessities of living beings. The energy of the pure oxygen is tempered, yet not too much weakened, by the admixture of nitrogen. The carbonic acid, which alone is noxious to life, is mixed in so minute a proportion as to be harmless to animals, while it is still beneficial to plants; and when the air is overloaded with watery vapour, it is provided that it shall descend in rain. These rains at the same time serve another purpose. From the surface of the earth there are continually ascending vapours and exhalations of a more or less noxious kind; these the rains wash out from the air, and bring back to the soil, at once purifying the atmosphere through which they descend, and refreshing and fertilizing the land on which they fall.

CHAPTER III.

Structure of plants—Mode in which their nourishment is obtained—Growth and substance of plants—Production of their substance from the food they imbibe—Mutual transformations of starch, sugar, and woody fibre.

From the compound substances, described in the preceding chapter, plants derive the greater portion of the carbon, hydrogen, oxygen, and nitrogen, of which their organic part consists. The living plant possesses the power of absorbing these compound bodies, of *decomposing* them in the interior of its several vessels, and of *recompounding* their elements in a different way, so as to produce new substances,—the ordinary products of vegetable life. Let us briefly consider the general structure of plants, and their mode of growth.

SECTION I.—OF THE STRUCTURE OF PLANTS, AND THE MODE IN WHICH THEIR NOURISHMENT IS OBTAINED.

A perfect plant consists of three several parts,—a root which throws out arms and fibres in every direction into the soil,—a trunk which branches into the air on every side,—and leaves which, from the ends of the branches and twigs, spread out a more or less extended surface into the surrounding air. Each of these parts has a peculiar structure and a special function assigned to it.

The *stem* of any of our common trees consists of three parts,—the pith in the centre, the wood surrounding the pith, and the bark which covers the whole. The pith consists of bundles of minute hollow tubes, laid horizontally one over the other; the wood and inner bark, of long tubes bound together in a vertical position, so as to be capable of carrying liquids up and down between the roots and the leaves. When a piece of wood is sawn across, the ends of these tubes may be distinctly seen. The branch is only a prolongation of the stem, and has a similar structure.

The *root*, immediately on leaving the trunk or stem, has also a similar structure; but as the root tapers away, the pith gradually disappears, the bark also thins out, the wood softens, till the white tendrils, of which its extremities are composed, consist only of a colourless spongy mass, full of pores, but in which no distinction of parts can be perceived. In this spongy mass the vessels or tubes which descend through the stem and root lose themselves, and by them these spongy extremities are connected with the leaves.

The *leaf* is an expansion of the twig. The fibres which are seen to branch out from the base over the inner surface of the leaf are prolongations of the vessels of the wood. The green exterior portion of the leaf is, in like manner, a continuation of the bark in a very thin and porous form. The green of the leaf, though full of pores, especially on the under part, yet also consists of, or contains, a collection of tubes or vessels, which stretch along its surface, and communicate with those of the bark.

Most of these vessels in the living plant are full of sap, and this sap is in almost continual motion. In spring and autumn the motion is more rapid, and in winter it is sometimes scarcely perceptible; yet the sap is supposed to be rarely quite stationary in every part of the tree.

From the spongy part of the root the sap ascends through the vessels of the *wood*, till it is diffused over the inner surface of the leaf by the fibres which the wood contains. Hence, by the vessels in the green of the leaf, it is returned to the bark, and through the vessels of the inner bark it descends to the root.

Every one understands why the roots send out fibres in every direction through the soil,—it is in search of water and of *liquid* food, which the spongy fibres suck in and send forward with the sap to the upper parts of the tree. It is to aid these roots in procuring food that, in the art of culture, such substances are mixed with the soil where these roots are, as are supposed to be necessary, or at least favourable, to the growth of the plant.

It is not so obvious that the leaves spread out their broad surfaces into the air for the same purpose precisely as that for which the roots diffuse their fibres through the soil. The only difference is, that while the roots suck in chiefly *liquid*, the leaves inhale almost solely *gaseous* food. *In the sunshine, the leaves are continually absorbing carbonic acid from the air and giving off oxygen gas.* That is to say, they are continually appropriating carbon from the air.* *When night comes, this process ceases, and they begin to absorb oxygen and to*

* Since carbonic acid, as shewn in the previous chapter, consists only of carbon and oxygen, they retain the carbon and reject the oxygen.

give off carbonic acid. But this latter process does not go on so rapidly as the former, so that, on the whole, plants when growing gain a large portion of carbon from the air. The actual quantity, however, varies with the season, with the climate, and with the kind of tree. The proportion of the whole carbon contained by a plant, which has been derived from the air, is greatly modified also by the quality of the soil in which it grows, and by the comparative abundance of liquid food which happens to be within reach of its roots. It has been ascertained, however, that in our climate, on an average, not less than from one-third to three-fourths of the entire quantity of carbon contained in the crops we reap from land of average fertility, is really obtained from the air.

We see then why, in arctic climates, where the sun once risen never sets again during the entire summer, vegetation should almost rush up from the frozen soil—the green leaf is ever gaining from the air and never losing, ever taking in and never giving off carbonic acid, since no darkness ever interrupts or suspends its labours.

How beautiful, too, does the contrivance of the expanded leaf appear! The air contains only one gallon of carbonic acid in 2500, and this proportion has been adjusted to the health and comfort of animals to whom this gas is hurtful. But to catch this minute quantity, the tree hangs out thousands of square feet of leaf in perpetual motion, through an ever-moving air; and thus, by the conjoined labours of millions of pores, the substance of whole forests of solid wood is slowly extracted from the fleeting winds. The green stem of the young shoot, and the green stalks of the grasses, also absorb carbonic acid as the green of the leaf does, and thus a larger supply is afforded when the growth is most rapid, or when the short life of the annual plant demands much nourishment within a limited time.

SECTION II.—OF THE GROWTH AND SUBSTANCE OF PLANTS.

In this way the perfect plant derives its food from the soil and from the air; but perfect plants arise from seeds; and the study of the entire life—the career, so to speak—of a plant, presents many interesting and instructive subjects of consideration.

When a portion of flour is made into dough, and this dough is kneaded with the hand under a stream of water upon a fine sieve, as long as the water passes through milky, there will remain on the sieve a glutinous sticky substance resembling birdlime, while the milky water will gradually deposit a pure white powder. This powder is *starch*, that which remains on the sieve is *gluten*. Both of these substances exist, therefore, in the flour; they both also exist in the grain. The starch consists of carbon, hydrogen, and oxygen only; the gluten, in addition to these, contains also nitrogen.

When ground into flour, these substances serve for food to man; in the unbruised grain they are intended to feed the future plant in its earliest infancy.

When a seed is committed to the earth, if the warmth and moisture are favourable, it begins to sprout. It pushes a shoot upwards, it thrusts a root downwards, but, until the leaf expand, and the root has fairly entered the soil, the young plant derives no nourishment other than water, either from the earth or from the air. It lives on the starch and gluten contained in the seed. But these substances, though capable of being separated from each other by means of water, as above stated, yet are neither of them soluble in water. Hence, they cannot, without undergoing a previous change, be taken up by the sap, and conveyed along the pores of the young shoot they are destined to feed. But it is so arranged that, when the seed first shoots, there is produced at the base of the germ, from a portion of the gluten, a small quantity of a substance (diastase) which has so powerful an effect upon the starch as immediately to render it soluble in the sap, which is thus enabled to take it up and convey it by degrees, just as it is wanted, to the shoot or to the root.* As the sap ascends, it becomes sweet,—the starch thus dissolved changes into sugar. When the shoot first becomes tipped with green, the sugar is again changed into the woody fibre, of which the stem of perfect plants chiefly consists. By the time that the food contained in the seed is exhausted,—often, as in the potato, long before,—the plant is able to live by its own exertions, at the expense of the air and the soil.

This change of the sugar of the sap into woody fibre is observable more or less in all plants. When they are shooting fastest the sugar is most abundant; not, however, in those parts which are grow-

* In malting barley, it is made to sprout a certain length, and the growth is then arrested by heating and drying it. Mashed barley, before sprouting, will not dissolve in water, but when sprouted, the whole of the starch (the flour) it contains dissolves readily by a gentle heat. The *diastase* formed during the germination effects this. By further heating in the brewer's wort, this starch is converted into sugar as it is in the growing plant.

ing, but in those which convey the sap to the growing parts. Thus the sugar of the ascending sap of the maple and the alder disappears in the leaf and in the extremities of the twig; thus the sugar-cane *sweetens* only a certain distance above the ground, up to where the new growth is proceeding; and thus also the young beet and turnip abound most in sugar, while in all these plants the sweet principle diminishes as the year's growth draws nearer to a close.

In the ripening of the ear also, the sweet taste, at first so perceptible, gradually diminishes and finally disappears; the sugar of the sap is here changed into the *starch* of the grain, which, as above described, is afterwards destined, when the grain begins to sprout, to be reconverted into sugar for the nourishment of the rising germ.

In the ripening of fruits a different series of changes presents itself. The fruit is first tasteless, then becomes sour, and at last sweet. In this case the acid of the unripe is changed into the sugar of the ripened fruit.

The substance of plants,—their solid parts that is—consist chiefly of *woody fibre*, the name given to the fibrous substance, of which wood evidently consists. It is interesting to inquire how this substance can be formed from the compounds, carbonic acid and water, of which the food of plants in great measure consists. Nor is it difficult to find an answer.

It will be recollected that the leaf drinks in carbonic acid from the air, and delivers back its oxygen, retaining only its carbon. It is also known that water abounds in the sap. Hence carbon and water are thus abundantly present in the pores or vessels of the green leaf. Now, woody fibre *consists only of carbon and water* chemically combined together,—100 lbs. of dry woody fibre consisting of 50 lbs. of carbon and 50 lbs. of water. It is easy, therefore, to see how, when the carbon and water meet in the leaf, woody fibre may be produced by their mutual combination.

If, again, we inquire how this important principle of plants may be formed from the other substances, which enter by their roots, from the ulmic acid, for example, the answer is equally ready. This acid also consists of carbon and water only, 50 lbs. of carbon with $37\frac{1}{2}$ of water forming ulmic acid, so that when it is introduced into the sap of the plant, all the materials are present from which the woody fibre may be produced.

Nor is it more difficult to see how starch may be converted into sugar, and this again into woody fibre; or how, again, sugar may be converted into starch in the ear of corn, or woody fibre into sugar during the ripening of the winter pear after its removal from the tree. *Any one of these substances may be represented by carbon and water only.* Thus,—

50 lbs. of carbon	with 50 of water,	make 100	of woody fibre.
50 lbs.	37½	87½	of ulmic acid.
50 lbs.	72½	122½	of cane sugar, of starch, or of gum.
50 lbs.	56	106	of vinegar.

In the interior of the plant, therefore, it is obvious that, whichever of these substances be present in the sap, the elements are at hand out of which any of the others may be produced. In what way they really are produced, the one from the other, and by what circumstances these transformations are favoured, it would lead into too great detail to attempt here to explain.*

We cannot help admiring to what varied purposes in nature the same elements are applied, and from how few and simple materials, substances, the most varied in their properties, are in the living vegetable daily produced.

* For fuller and more precise explanations on these interesting topics, see the Author's LECTURES *on Agricultural Chemistry and Geology*, Part I.

CHAPTER IV.

Of the Inorganic Constitution of Plants—Their immediate Source—Their Nature—Quantity of each in certain common Crops.

SECTION I.—SOURCE OF THE EARTHY MATTER OF PLANTS —SUBSTANCES OF WHICH IT CONSISTS.

WHEN plants are burned, they always leave more or less of ash behind. This ash varies in quantity in different plants, in different parts of the same plant, and sometimes in different specimens of the same kind of plant, especially if grown upon different soils; yet it is never wholly absent. It seems as necessary to their existence in a state of perfect health as any of the elements which constitute the organic or combustible part of their substance. They must obtain it therefore along with the food on which they live: it is in fact a part of their natural food, since without it they become unhealthy. We shall speak of it therefore as the *inorganic food* of plants.

We have seen that all the elements which are necessary to the production of the woody fibre, and of the other organic parts of the plant, may be derived either from the air, from the carbonic acid and watery vapour taken in by the leaves, or from the soil, through the medium of the roots. In the air, however, only rare particles of inorganic or earthy matter are known to float, and these in a solid form, so as to be unable to enter by the leaves; the earthy matter which constitutes the ash, therefore, must be all derived from the soil.

The earthy part of the soil, therefore, serves a double use. It is not merely, as some have supposed, a substratum in which the plant may so fix and root itself, as to be able to maintain its upright position against the force of winds and tempests; but it is a storehouse of food also, from which the roots of the plant may select such earthy substances as are necessary to, or are fitted to promote, its growth.

The ash of plants consists of a mixture of several, sometimes of as many as eleven, different earthy substances. These substances are the following :—

1. *Potash.*—The common pearl-ash of the shops is a compound of potash with carbonic acid; it is a *carbonate of potash.* By dissolving the pearl-ash in water, and boiling it with quicklime, the carbonic acid is separated, and potash alone, or caustic potash, as it is often called, is obtained.

2. *Soda.*—The common soda of the shops is a *carbonate of soda,* and by boiling it with quick-lime, the carbonic acid is separated, as in the case of pearl-ash.

3. *Lime.*—This is familiar to every one as the *lime-shells,* or unslaked lime of the limekilns. The unburned limestone is a *carbonate of lime;* the carbonic acid in this case being separated by the roasting in the kiln.

4. *Magnesia.*—This is the calcined magnesia of the shops. The uncalcined is a *carbonate of magnesia,* from which heat drives off the carbonic acid.

5. *Silica.*—This is the name given by chemists to the substance of flint, quartz, and of siliceous sands and sandstones.

6. *Alumina* is the pure earth of alum, obtained by dissolving alum in water, and adding liquid ammonia (hartshorn) to the solution. It forms about two-fifths of the weight of porcelain and pipe-clays, and of some other very stiff kinds of clay.

7. *Oxide of Iron.*—The most familiar form of this substance is the rust that forms on metallic iron in damp places. It is a compound of iron with oxygen, hence the name *oxide.*

8. *Oxide of Manganese* is a brown powder, which consists of oxygen in combination with a metal resembling iron, to which the name of manganese is given. It exists in plants, and in soils only in very small quantity.

9. *Sulphur.*—This substance is well known. It generally exists in the ash in the state of *sulphuric acid* (oil of vitriol), which is a compound of sulphur with oxygen. It does not always exist in living plants, however, in this state.

Sulphuric acid forms with potash a *sulphate of potash,*—with soda, *sulphate of soda* (or Glauber's salts),—with lime, *sulphate of lime* (gypsum),—with magnesia, *sulphate of magnesia* (Epsom salts),—with alumina, *sulphate of alumina,*—and with oxide of iron, *sulphate of iron* or green vitriol. When the sulphate of potash is combined with sulphate of alumina, it forms common alum.

10. *Phosphorus* is a soft pale yellow substance which readily takes fire in the air, and gives off, while burning, a dense white smoke. The white fumes which form this smoke are a compound of phosphorus with oxygen obtained from the air,

and are called *phosphoric acid.* In the ash of plants the phosphorus is found in the state of phosphoric acid, though it probably does not all exist in the living plant in that state.

Phosphoric acid forms *phosphates* with potash, soda, lime, and magnesia. When bones are burned, a large quantity of a white earth remains (bone earth), which is a *phosphate of lime,* consisting of lime and phosphoric acid. Phosphate of lime is generally present in the ash of plants; phosphate of magnesia is contained most abundantly in the ash of wheat and other varieties of grain.

11. *Chlorine.*—This is a very suffocating gas, which gives its peculiar smell to chloride of lime, and is used for bleaching and disinfecting. It is readily obtained by pouring muriatic acid (spirit of salt) on the black oxide of manganese of the shops. In combination with the metallic bases of potash, soda, lime, and magnesia, it forms the *chlorides* of potassium, sodium (common salt), calcium and magnesium,* and in one or other of these states it generally enters into the roots of plants, and exists in their ash.

* Potash, soda, lime, and magnesia, are compounds of the metals here named with oxygen. It is a very striking fact, that the suffocating gas chlorine, when combined with sodium, a metal which takes fire when placed upon water, should form the agreeable and necessary condiment, *common salt.*

Such are the inorganic substances usually found mixed or combined together in the ash of plants. It has already been observed, that the quantity of ash left by a given weight of vegetable matter varies with a great many conditions. This fact deserves a more attentive consideration.

SECTION II.—OF THE DIFFERENCE IN THE QUANTITY OF ASH.

1. The quantity of ash yielded by *different plants* is unlike. Thus 1000 lbs. of

Wheat	leave	12 lbs.	Barley	leave	25 lbs.
Oats	...	26 lbs.	Potatoes	...	8 lbs.
Turnips	...	8 lbs.	Carrots	...	7 lbs.
Red Clover	...	16 lbs.	White Clover	...	17 lbs.
Rye Grass	...	17 lbs.			

So that the quantity of inorganic food required by different vegetables is greater or less according to their nature; and if a soil be of such a kind that it can yield only a small quantity of this inorganic food, then only those plants will grow well upon it which require the least. Hence, trees may often grow where arable crops fail to thrive, because many of them require and contain very little inorganic matter. Thus while 1000 lbs. of elm wood leave 19 lbs. and of poplar 20 lbs. of ash, the same weight of the willow leaves only $4\frac{1}{2}$ lbs., of the beech 4 lbs., of the birch $3\frac{1}{2}$ lbs., of different pines less than 3 lbs., and of the oak only 2 lbs. of ash when burned.

2. The quantity of inorganic matter varies in *different parts of the same plant.* Thus while 1000 lbs. of the turnip root sliced and dried in the air leave 70 lbs. of ash, the dried leaves give 130 lbs.; and while the grain of wheat yields only 12 lbs. wheat straw will yield 60 lbs. of earthy matter. So, though the willow and other *woods* leave little ash, as above stated, yet the willow leaf leaves 82 lbs., the beech leaf 42 lbs., the birch 50 lbs., the different pine leaves 20 lbs. to 30 lbs., and the leaves of the elm as much as 120 lbs. of incombustible matter when burned in the air.

Most of the inorganic matter, therefore, which is withdrawn from the soil in a crop of corn is returned to it again, by the skilful husbandman, in the fermented straw,—in the same way as nature, in causing the trees periodically to shed their leaves, returns with them to the soil a very large portion of the soluble inorganic substances which had been drawn from it by the roots during the season of growth.

Thus an annual top-dressing is given to the land where forests grow; and that which the roots from spring to autumn are continually sucking up, and carefully collecting from considerable depths, winter strews again on the surface, so as, in the lapse of time, to form a soil which cannot fail to prove fertile,—because it is made up of those very materials of which the inorganic substance of former races of vegetables has been entirely composed.

2. The quantity of inorganic matter often differs in *different specimens of the same plant.* Thus, 1000 lbs. of wheat straw, grown at different places, gave to four different experimenters 43, 44, 35, and 155 lbs. of ash respectively. Wheat straw, therefore, does not always leave the same quantity of ash.

To what is this difference owing? Is it to the nature of the soil, or does it depend upon the *variety* of wheat experimented upon? It seems to depend partly upon both. Thus, on the same field, in Ravensworth dale, Yorkshire, on a rich clay soil abounding in lime, the *Golden Kent* and *Flanders Red* wheats were sown in the spring of 1841. The former gave an excellent crop, while the latter was a total failure, the ear containing 20 or 30 grains only of poor wheat. The straw of the former left 165 lbs. of ash from 1000 lbs., that of the latter only 120 lbs. Something, therefore, depends upon the variety. But as from the straw of a good wheat crop grown near Durham this last summer on a clay loam I obtained only 66 lbs. of ash, I am persuaded that the very wide variations in the quantity of ash left, by different wheat straws, must be dependent in some considerable degree upon the soil.

The truth, so far as it can as yet be made out, seems to be this—that every plant must have a certain quantity of inorganic matter to make it grow in the most healthy manner;—that it is capable of living, growing, and even ripening seed with very much less than this quantity;—but that those soils will produce the most perfect plants which can best supply all their wants,—and that the best seed will be raised in those districts where the soil, without being too rich or rank, yet can yield both organic and inorganic food in such proportions as to maintain the corn plants in their most healthy condition.

SECTION III.—OF THE QUALITY OF THE ASH OF PLANTS.

But much also depends upon the *quality* as well as upon the *quantity* of the ash. Plants may leave the same weight of ash when burned, and yet the nature of the two specimens of ash, the kind of matter of which they respectively consist, may be very different. The ash of one may contain much lime, of another much potash, of a third much soda, while in a fourth much silica may be present. Thus 100 lbs. of the ash of *bean* straw contain 53½ lbs. of potash, while that of *barley* straw contains only 3½ lbs. in the hundred ; and, on the other hand, the same weight of the ash of the latter contains 73½ lbs. of silica, while in that of the former there are only 7½ lbs.

The quality of the ash seems to vary with the same conditions by which its quantity is affected. Thus—

1. It varies with the kind of plant. 100 lbs. of the ash of wheat, barley, and oats, for example, contain, respectively,

	Wheat.	Barley.	Oats.
Potash, ...	19	12	6
Soda, ...	20½	12	5
Lime, ...	8	4½	3
Magnesia, . . .	8	8	2½
Alumina, . . .	2	1	½
Oxide of Iron, . .	0	trace.	1½
Silica, ...	34	50	76½
Sulphuric acid, . .	4	2½	1½
Phosphoric acid, . .	3½	9	3
Chlorine, ...	1	1	½
	100	100	100

A comparison of the several numbers opposite to each other in these three columns, shews how unlike the quantities of the different substances are, which are contained in an equal weight of the ash of these three varieties of grain. The ash of wheat contains 19 lbs. of potash in the 100 lbs., while that of oats contains only 6 lbs. In wheat are $20\frac{1}{2}$ per cent. of soda, in oats only 5 per cent. Wheat also contains more sulphuric acid than either of the other grains, while barley contains a still greater predominance of phosphoric acid.

It is thus evident that a crop of wheat will carry off from the soil—even suppose the whole *quantity* of ash left by each the same in weight—very different quantities of potash, soda, &c. from a crop of oats. It will take more of these, of sulphuric acid, and of certain other substances, from the soil. It will, therefore, exhaust the soil more of *these* substances—as barley and oats will of others—hence *one* reason why a piece of land may suit one of these crops and not suit the others. That which cannot grow wheat may yet grow oats. Hence, also, two successive crops of *different* kinds of grain may grow where it would greatly injure the soil to take two in succession of the *same* kind, especially of either wheat or barley; and hence we likewise deduce one natural reason for a rotation of crops. The surface soil may be so far exhausted of one inorganic substance, that it cannot afford it in sufficient quantity during the present season to bring a given crop to healthy maturity, and yet may, by natural processes, be so far supplied again, during the intermediate growth of certain other crops, as to be prepared in a future season fully to supply all the wants of the same crop, and to yield a plentiful harvest.

2. The kind of inorganic matter varies with the *part* of the plant. Thus the grain and the straw of the corn plants contain very unlike quantities of the several inorganic constituents, as will appear by comparing the following with the preceding table:—

	Wheat Straw.	Barley Straw.	Oat Straw
Potash, . . .	½	3½	15
Soda, . . .	¾	1	trace.
Lime, . . .	7	10½	2¾
Magnesia, . .	1	1½	½
Alumina, . . .	2¾	3	trace.
Oxide of Iron, . . } Oxide of manganese, }	0	½	trace.
Silica, . . .	81	73½	80
Sulphuric acid, .	1	2	1½
Phosphoric acid, .	5	3	¼
Chlorine, . . .	1	1½	trace.
	100	100	100

Not only are the quantities of the several inorganic substances contained in these different kinds of straw very unlike—especially the proportions of potash, lime, and phosphoric acid in each—but these quantities are also very different from those exhibited by the numbers in the preceding table as contained in the three varieties of grain. In this difference we see, further, *one* reason why the same soil which may be favourable to the growth of straw may not be equally propitious to the growth of the ear. Wheat straw contains little either of potash or of soda ; the ash of the grain contains a large proportion ; while the ash of the oat-straw, on the other hand, contains a much larger proportion of potash than that of its own ear does. It is clear, therefore, that the roots may, in certain plants and in certain soils, succeed in fully nourishing the straw while they cannot fully ripen the ear ; or contrariwise, where they feed but a scanty straw, may yet *be able* to give ample sustenance to the filling ear.*

3. The quality of the ash varies also with the soil in which it grows. This will be understood from what is stated above. Where the soil is favourable, the roots can send up into the straw

* And occasionally *do* give ; for a plump grain, and even a well-filled ear, are not unfrequently found where the straw is unusually deficient.

every thing which the healthy plant requires; when it is poorly supplied with some of those inorganic constituents which the plant desires, life may be prolonged, a stunted or unhealthy crop may be raised, in which the kind, and perhaps the quantity, of ash left in burning will necessarily be different from that left by the same species of plant grown under more favouring circumstances. Of this fact there can be no doubt, though the extent to which such variations may take place without absolutely killing the plant, has not yet been by any means made out.

4. It varies also with the period of a plant's growth, or the season at which it is reaped. Thus, in the young leaf of the turnip and potato, a greater proportion of the inorganic matter they contain consists of potash than in the old leaf. The same is true of the stalk of wheat; and similar differences prevail in almost every kind of plant at different stages of its growth.

The enlightened agriculturist will perceive that all the facts above stated have a perceptible connection with the ordinary processes of practical agriculture, and tend to throw considerable light on some of the principles by which they ought to be regulated. One illustration of this is exhibited in the following section.

SECTION IV.—QUANTITY OF INORGANIC MATTER CONTAINED IN AN ORDINARY CROP OR SERIES OF CROPS.

The importance of the inorganic matter contained in living vegetables, or in vegetable substances when reaped and dry, will appear more distinctly if we consider the actual quantity carried off from the soil in a series of crops.

In a four-years' course of cropping, in which the crops gathered amount per acre to—

1st year, *Turnips*, 25 tons of bulbs, and 7 tons of tops.

2d year, *Barley*, 38 bushels of 63 lbs. each, and 1 ton of straw.

3d year, *Clover and Rye-Grass*, 1 ton of each in hay.

4th year, *Wheat*, 25 bushels of 60 lbs., and 1¾ tons of straw.

The quantity of inorganic matter carried off in the four crops, supposing none of them to be eaten on the land, amounts to—

Potash, . . .	281 lbs.	Silica, . . .	318 lbs.
Soda, ...	130 "	Sulphuric acid,	111 "
Lime, . . .	242 "	Phosphoric acid,	61 "
Magnesia, .	42 "	Chlorine, .	39 "
Alumina, . .	11 "		
		Total,	1240

or, in all, about 11 cwt.—of which gross weight the different substances form very unlike proportions.

A still clearer idea of these quantities will be obtained by a consideration of the fact, that if we carry off the entire produce, and return none of it again in the shape of manure, we must or ought in its stead, if the land is to be restored to its original condition, add to each acre every four years :—

Pearl or Pot-ash, . .	390 lbs.	at a cost of	*l.*3	10	0
Crystallized carbonate of soda,	440	...	2	5	0
Common salt, . . .	65	...	0	2	0
Quick (burned) lime, .	240	...	0	1	0
Epsom salts, ...	250	...	1	5	0
Alum, ...	84	...	0	8	0
Bone dust, . . .	260	...	0	16	0
Total,	1729	...	*l.*8	7	0

Several observations suggest themselves from a consideration of the above statements : *first*, that if this inorganic matter be really necessary to the plant, the gradual and constant removal of it from the land ought by and by to impoverish the soil of this inorganic food ; *second*, that the more of what grows upon the land we can again return to it in manure, the less will this deterioration be perceptible ; *third*, that as many of these inorganic substances are readily soluble in water, the liquid manure of the farm-yard, so often allowed to run to waste, carries with it to the rivers much of the saline matter that ought to be returned to the land; and, *lastly*, that the utility and often indispensable necessity of certain artificial manures is owing, it may be, in some districts, to the natural poverty of the land in certain inorganic substances,—but more frequently to a want of acquaintance with the facts above stated, among practical men, and to the long continued neglect and waste which has been the natural consequence.

In certain districts, the soil and subsoil contain within themselves an almost unfailing supply of some of these inorganic substances, so that the waste is long in being felt; in others they become sooner exhausted, and hence call for more care, and, when exhausted, for a more expensive cultivation, in order to replace them.

One thing is of essential importance to be remembered by the practical farmer—that the deterioration of land is often an exceedingly slow process. In the hands of successive generations a field may so imperceptibly become less valuable, that a century even may elapse before the change prove such as to make a sensible diminution in the valued rental. Such slow changes, however, have been seldom recorded; and hence the practical man is occasionally led to despise the clearest theoretical principles, because he has not happened to see them verified in his own limited experience, and to neglect therefore the suggestions and the wise precautions which these principles lay before him.

The agricultural history of tracts of land of different qualities, shewing how they had been cropped and tilled, and the average produce in grain, hay, straw, and other crops, every five years, during an entire century, would be invaluable materials both to theoretical and to practical agriculture.

CHAPTER V.

Of Soils—their Organic and Inorganic Portions—Saline Matter in Soils—Examination and Classification of Soils—Diversities of Soils and Subsoils.

Soils consist of two parts,—of an *organic* part, which can readily be burnt away when the soil is heated to redness; and of an *inorganic* part, which is fixed in the fire, and which consists entirely of earthy and saline substances.

SECTION I.—OF THE ORGANIC PART OF SOILS.

The organic part of soils is derived chiefly from the remains of vegetables and animals which have lived and died in or upon the soil, which have been spread over it by rivers and rains, or which have been added by the hand of man for the purpose of increasing its natural fertility.

This organic part varies very much in quantity in different soils. In some, as in peaty soils, it forms from 50 to 70 per cent. of their whole weight, and even in some rich long cultivated lands it has been found, in a few rare cases, to amount to as much as 25 per cent. In general, however, it is present in much smaller proportion, even in our best arable lands. Oats and rye will grow upon a soil containing only $1\frac{1}{2}$ per cent., barley when 2 to 3 are present, while good wheat soils generally contain from 4 to 8 per cent. In stiff and very clayey soils 10 to 12 per cent. may occasionally be detected. In very old pasture lands and in gardens, vegetable matter occasionally accumulates, so as to overload the upper soil.

To this organic matter in the soil the name of *humus* has been given by some writers. It contains or yields to the plant the ulmic and humic acids described in a previous chapter. It supplies also, by its decay, in contact with the air which penetrates the soil, much carbonic acid, which is supposed to enter the roots and minister to the growth of living vegetables. During the same decay ammonia is likewise produced,—and in larger quantity, if animal matter be present in considerable abundance,—which ammonia is found to promote vegetation in a remarkable manner. Other substances, more or less nutritious, are also formed from it in the soil. These enter by the roots, and contribute to nourish the growing plant, though the extent to which it is fed from this source is dependent, both upon the abundance with which these substances are supplied, and upon the nature of the plant itself, and of the climate in which it grows.

Another influence of this organic portion of the soil, whether naturally formed in it, or added to it as manure, is not to be neglected. It contains, —as we have seen that all vegetable substances do,—a considerable quantity of inorganic, that is, of saline and earthy matter, which is liberated as the organic part decays. Thus living plants derive from the remains of former races buried beneath the surface, a portion of that inorganic food which can only be obtained in the soil,—and which, if not thus directly supplied, must be sought for by the slow extension of their roots through a greater depth and breadth of the earth in which they grow. The addition of manure to the soil, therefore, places within the easy reach of the roots not only organic but inorganic food also.

SECTION II.—OF THE INORGANIC PART OF SOILS.

The inorganic part of soils,—that which remains behind, when every thing combustible is burned away by heating it to redness in the open air,—consists of two portions, one of which is *soluble* in water, the other *insoluble*. The soluble consists of *saline* substances, the insoluble of *earthy* substances.

1. *The saline or soluble portion*.—In this country the surface soil of our fields, in general, contains very little soluble matter. If a quantity of soil be dried in an oven, a pound weight of it taken, and a pint and a half of pure boiling rain-water poured over it, the whole well stirred and allowed to settle,—the clear liquid, when poured off and boiled to dryness, may leave from 2 to 20 grains of saline matter. This saline matter will consist of common salt, gypsum, sulphate of soda (Glauber's salts), sulphate of magnesia (Epsom salts), with traces of the chlorides of calcium, magnesium, and potassium, and of the nitrates of potash, soda, and lime.* It is from these soluble substances that the plants derive the greater portion

* See pages 51 and 52, where these substances are described.

of the saline ingredients contained in the ash they leave when burned.

Nor must the quantity thus obtained from a soil be considered too small to yield the whole supply which a crop requires. A single grain of saline matter in every pound of a soil a foot deep, is equal to 500 lbs. in an acre, which is more than is carried off from the soil in 10 rotations (40 years), where only the wheat and barley are sent to market, and the straw and green crops are regularly returned to the land in the manure.*

In some countries, indeed in some districts of our own country, the quantity of saline matter in the soil is so great, as in hot seasons to form a distinct incrustation on the surface. This may often be seen in the neighbourhood of Durham; and is more especially to be looked for in districts where the subsoil is sandy and porous, and more or less full of water. In hot weather the evaporation on the surface causes the water to ascend from the porous subsoil: and as this water always brings with it a quantity of saline matter,—which it leaves behind when it rises in vapour,—it is evident that the longer the dry weather and the consequent

* A further portion, it will be recollected, is carried off in the cattle that are sent to market,—this is here neglected.

evaporation from the surface continue, the thicker the incrustations will be, or the greater the accumulation of saline matter on the surface. Hence, where such a moist and porous subsoil exists in countries rarely visited by rain, as in the plains of Peru, of Egypt, or of India, the country is whitened over in the dry season with an unbroken covering of the different saline substances above mentioned.

When rain falls, the saline matter is dissolved, and descends again to the subsoil,—in dry weather it reascends. Thus the surface soil of any field will contain a larger proportion of soluble inorganic matter in the middle of a hot season than in one of even ordinary rain ; and hence the fine dry weather which, in early summer, hastens the growth of corn, and later in the season favours its ripening, does so, among its other modes of action, by bringing up to the roots from beneath a more ready supply of those saline compounds which the crop requires for its healthful growth.

2. *The earthy or insoluble portion.*—The earthy or insoluble portion of soils rarely constitutes less than 95 lbs. in a hundred of their whole weight. It consists chiefly of *silica* in the form of *sand*, of *alumina* in the form of *clay*, and of *lime* in the form of *carbonate of lime*. It is rarely

free, however, from one or two per cent. of oxide of iron ; and where the soil is of a red colour, this oxide is present in a still larger quantity. A trace of magnesia also may be almost always detected, and a minute quantity of phosphate of lime. The principal ingredients, however, of the earthy part of all soils are sand, clay, and lime ; and soils are named or classified according to the quantities of each of these three they may happen to contain.

If an ounce of soil be boiled in a pint of water till it is perfectly softened and diffused through it, and, after shaking, the heavy parts be allowed to settle for a few minutes, the sand will subside, while the clay—which is in finer particles, and is less heavy—will still remain floating. If the water and clay be now poured into another vessel, and be allowed to stand till the water has become clear, the sandy part of the soil will be on the bottom of the one vessel, the clayey part on that of the other, and they may be dried and weighed separately.

If 100 grains of dry soil leave no more than 10 of clay, it is called a *sandy soil ;* if from 10 to 40, a *sandy loam ;* if from 40 to 70, a *loamy soil ;* if from 70 to 85, a *clay loam ;* from 85 to 95, a *strong clay soil ;* and when no sand is separated at all by this process, it is a pure *agricultural clay.*

The *strong clay soils* are such as are used for making tiles and bricks; the pure *agricultural clay* is such as is commonly employed for the manufacture of pipes (pipe clay).

Soils consist of these three substances *mixed* together. The pure *clay* is a chemical *compound* of silica and alumina, in the proportion of about 60 of the former to 40 of the latter. Pure clay soils rarely occur—it being well known to all practical men, that the strong clays (tile clays) which contain from 5 to 15 per cent. of sand, are brought into arable cultivation with the greatest possible difficulty. It will rarely happen, therefore, that arable land will contain more than 30 to 35 of alumina.

If a soil contain more than 5 per cent. of carbonate of lime, it is called a *marl*; if more than 20 per cent., it is a *calcareous* soil. *Peaty soils*, of course, are those in which the vegetable matter predominates very much.

To estimate the lime, a quantity of the soil should be burned in the air, and a weighed portion, 100 or 200 grains, diffused through half a pint of cold water mixed with half a wine glassful of spirit of salt (muriatic acid), and allowed to stand for a couple of hours, with occasional stirring. The water is then poured off, the soil dried, heated to redness as before, and weighed: the loss is nearly all lime.*

The quantity of vegetable or other organic matter is determined by drying the soil *well* upon paper in an oven, and then burning a weighed quantity in the air: the loss is *nearly all* organic matter. In stiff clays this loss will comprise a portion of water, which is not wholly driven off from such soils by drying upon paper in the way described.

SECTION III.—OF THE DIVERSITIES OF SOILS AND SUBSOILS.

Though the substances of which soils *chiefly* consist are so few in number, yet every practical man knows how very diversified they are in character—how very different in agricultural value. Thus, in some of our southern counties, we have a white soil, consisting apparently of nothing else but chalk; in the centre of England a wide plain of dark red land; in the border counties of Wales, and on many of our coal-fields, tracts of country almost perfectly black; while yellow, white, and brown sands give the prevailing character to the

* Unless the soil happen to contain a large quantity of magnesia, which is rarely the case.

soils of other districts. Such differences as these arise from the different proportions in which the sand, lime, clay, and the oxide of iron which colours the soils, have been mixed together.

But how have they been so mixed—differently in different parts of the country. By what natural agency?—for what end?

Again, the soil on the surface rests on what is usually denominated the *subsoil*. This, also, is very various in its character and quality. Sometimes it is a porous sand or gravel, through which water readily ascends from beneath or sinks in from above; sometimes it is light and loamy like the soil that rests upon it; sometimes stiff and impervious to water.

The most ignorant farmer knows how much the value of a piece of land depends upon the characters of the surface soil,—the intelligent improver understands best the importance of a favourable subsoil. "When I came to look at this farm," said an excellent agriculturist to me, "it was spring, and damp growing weather: the grass was beautifully green, the clover shooting up strong and healthy, and the whole farm had the appearance of being very good land. Had I come in June, when the heat had drunk up nearly all the moisture which the *sandy subsoil* had left in the surface, I should not have offered so much rent for it by ten shillings an acre." He might have said also, "Had I taken a spade, and dug down 18 inches in various parts of the farm, I should have known what to expect in seasons of drought."

But how come subsoils thus to differ—one from the other—and from the surface soil that rests upon them? Are there any principles by which such differences can be accounted for—by which they can be foreseen—by the aid of which we can tell what kind of soil may be expected in this or that district—even without visiting the spot—and on what kind of subsoil it is likely to rest?

Geology explains the cause of all such differences, and supplies us with principles by which we can predict the general quality of the soil and subsoil in the several parts of entire kingdoms;—and where the soil is of inferior quality and yet susceptible of improvement, the same principles indicate whether the means of improving it are likely, in any given locality, to be attainable at a reasonable cost.

It will be proper shortly to illustrate these direct relations of geology to agriculture.

CHAPTER VI.

Direct relations of Geology to Agriculture—Origin of Soils—Causes of their Diversity—Relation to the Rocks on which they rest—Constancy in the relative Position and Character of the Stratified Rocks—Relation of this fact to Practical Agriculture—General Character of the Soils upon these Rocks.

GEOLOGY is that branch of knowledge which embodies all ascertained facts in regard to the nature and internal structure, both physical and chemical, of the solid parts of our globe. This science has many close relations with practical agriculture, and especially throws much light on the nature and origin of soils,—on the cause of their diversity,—on the kind of materials by the admixture of which they may be permanently improved,—and on the sources from which these materials may be derived.

SECTION I.—OF THE ORIGIN OF SOILS.

If we dig down through the soil and subsoil to a sufficient depth, we always come sooner or later to the solid rock. In many places the rock actually reaches the surface, or rises in cliffs, hills, or ridges, far above it. The surface (or crust) of our globe, therefore, consists everywhere of a solid mass of rock, overlaid with a covering, generally thin, of loose materials. The upper or outer part of these loose materials forms the soil.

The geologist has travelled over great part of the earth's surface, has examined the nature of the rocks, which everywhere repose beneath the soil, and has found them to be very unlike in character, in composition, and in hardness—in different countries and districts. In some places he has met with a sandstone, in other places a limestone, in others a slate or hardened rock of clay. But a careful comparison of all the kinds of rock he has observed, has led him to the general conclusion, *that they are all either sandstones, limestones, or clays of different degrees of hardness, or a mixture in different proportions of two or more of these kinds of matter.*

When the loose covering of earth is removed from the surface of any of these rocks, and it is left exposed, summer and winter, to the action of the winds and r ins and frosts, it may be seen gradually to crumble away. Such is the case even with many of those which, on account of their greater hardness, are employed as building-stones, and are kept generally dry; how much more with such as are less hard, and, beneath a covering of moist earth, are continually exposed to the action of water. The natural crumbling of a naked rock thus gradually covers it with loose materials, in which seeds fix themselves and vegetate, and which eventually forms a soil. The soil thus produced partakes necessarily of the character of the rock on which it rests, and to the crumbling of which it owes its origin. If the rock be a sandstone the soil is sandy; if a claystone, it is a more or less stiff clay; if a limestone, it is more or less calcareous; and if the rock consist of any peculiar mixture of those three substances, a similar mixture is observed in the earthy matter into which it has crumbled.

Led by this observation, the geologist, after comparing the rocks of different countries with one another, compared next the soils of various districts with the rocks on which they immediately rest. The *general* result of this comparison has been, that in almost every country the soils have as close a resemblance to the rocks beneath them—as the loose earth derived from the crumbling of a rock before our eyes, bears to the rock of which it lately formed a part. The conclusion therefore is irresistible, that soils, generally speaking, have been formed by the crumbling or decay of the solid rocks,—that there was a time when these rocks were uncovered by any loose materials,—and that the accumulation of soil has been the slow result of the natural degradation (wearing away) of the solid crust of the globe.

SECTION II.—CAUSE OF THE DIVERSITY OF SOILS.

The cause of the diversity of soils in different districts, therefore, is no longer obscure. If the subjacent rocks in two localities differ, the soils met with there must differ also, and in an equal degree.

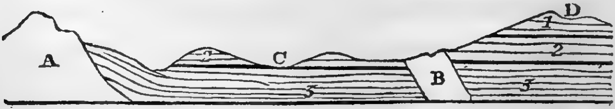
But why, it may be asked, do we find the soil in some countries uniform, in mineral* character and general fertility, over hundreds or thousands of square miles, while in others it varies from field

* That is, containing the same general proportions of sand, clay, lime, &c., or coloured red by similar quantities of oxide of iron.

to field,—the same farm often presenting many well marked differences both in mineral character and in agricultural value? The cause of this is to be found in the mode in which the different rocks are observed to lie, one upon or by the side of the other.

Geologists distinguish rocks into two classes, the *stratified* and the *unstratified*. The former are found lying over each other in separate beds or *strata*, like the leaves of a book, when laid on its side, or like the layers of stones in the wall of a building; the latter form hills, mountains, or sometimes ridges of mountains, consisting of one more or less solid mass of the same material, in which no layers or strata are any where distinctly perceptible. Thus, in the following diagram, (No. 1,) A and B represent *unstratified* masses, in connection with a series of *stratified* deposits, 1, 2, 3, lying over each other in a horizontal position. On A one kind of soil will be formed, on C another, on B a third, and on D a fourth,—the rocks being all different from each other.

No. 1.



If from A to D be a wide valley of many miles in extent, the undulating plain at the bottom of the valley, resting in great part on the same rock (2), will be covered by a similar soil. On B the soil will be different for a short space; and again at C, and on the first ascent to A, where the rock (3) rises to the surface. In this case the stratified rocks lie horizontally; and it is the undulating nature of the country which, bringing different kinds of rock to the surface, causes a necessary diversity of soil.

But the degree of *inclination*, which the beds possess, is a more frequent cause of variation in the characters of the soil in the same district, and even at shorter distances. This is shewn in the annexed diagram (No. 2), where A, B, C, D, E, represent the mode in which the stratified rocks of a district of country not unfrequently occur in connection with each other.

No. 2.

Proceeding from E in the plain, the soil would change when we came upon the rock D, but would then continue uniform till we reached the layer C. Each of these layers may stretch over a comparatively level tract of perhaps hundreds of miles in extent. Again, on climbing the hill-side, another soil would present itself, which would not change till we arrived at B. Then, however, we begin to walk over the edges of the beds, and the soil may vary with every new *stratum* (or bed) we pass over, till we gain the ascent to A, where the beds are much thinner, and where, therefore, still more frequent variations may present themselves.

Everywhere over the British islands valleys are hollowed out, as in the former of these diagrams (No. 1), by which the rocks beneath are exposed, and differences of soil produced,—or the beds are more or less inclined, as in the latter diagram (No. 2), causing still more frequent variations of the land to appear. By a reference to these facts, nearly all the *great* diversities which the soils of the country present may be satisfactorily accounted for.

SECTION III.—OF THE CONSTANCY IN THE CHARACTER AND ORDER OF SUCCESSION OF THE STRATIFIED ROCKS.

Another fact alike important to agriculture and to geology, is the natural order or mode of arrangement in which the stratified rocks are observed to occur in the crust of the globe. Thus, if 1, 2, 3, in diagram No. 1 represent three different kinds of rock, a limestone, for example, a sandstone, and a hard clay rock (a shale or slate), lying over each other, in the order here represented; then, in whatever part of the country nay, in whatever part of the world, these same rocks are met with, they will always be found in the same relative position. The bed 2 or 3 will never be observed to lie over the bed 1.

This fact is important to geology, because it enables this science to arrange all the stratified rocks in a certain invariable order,—which order indicates their relative age or antiquity,—since that which is lowest, like the lowest layer of stones in the wall of a building, must generally have been the first deposited, or must be the oldest. It also enables the geologist, on observing the kind oı rock which forms the surface in any country, to predict at once, whether certain other rocks are likely to be met with in that country or not. Thus at C (diagram, No. 1), where the rock (3) comes to the surface, he knows it would be in vain, either by sinking or otherwise, to seek for the rock (1), the natural place of which is far above it; while at D he knows that by sinking he is likely to find either 2 or 3, if it be worth his while to seek for them.

To the agriculturist this fact is important, among other reasons,—

1. Because it enables him to predict whether certain kinds of rock, which might be used with advantage in improving his soil, are likely to be met with within a reasonable distance or at an accessible depth. Thus if the bed D (diagram No. 2) be a limestone, the instructed farmer at E knows that it is not to be found by sinking into his own land, and, therefore, brings it from D; while, to the farmer upon C, it may be less expensive to dig down to the bed D in one of his own fields, than to cart it from a distant spot where it occurs on the surface. Or if the farmer requires clay, or marl, or sand, to ameliorate his soil, this knowledge of the constant relative position of beds enables him to say where these materials are to be got, or where they are to be looked for, and whether the advantage to be derived is likely to repay the cost of procuring them.

2. It is observed, that when the soil on the surface of each of a series of rocks, such as C, or D, or E, in the same diagram, is uniformly bad, it is almost invariably of better quality at the point where the two rocks meet. Thus C may be dry, sandy, and barren; D may be cold, unproductive clay; and E a more or less unfruitful limestone

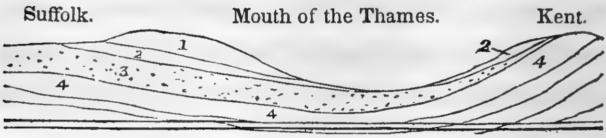
soil: yet at either extremity of the tract D, where the soil is made up of an admixture of the decayed portions of the two adjacent rocks, the land may be of average fertility—the sand of C may adapt the adjacent clay to the growth of turnips, while the lime of E may cause it to yield large returns of wheat.* Thus, to the tenant in looking out for a farm, or to the capitalist in seeking an eligible investment, a knowledge of the mutual relations of geology and agriculture will often prove of the greatest assistance. Yet how little is such really useful knowledge diffused among either class of men—how little are either tenants or proprietors guided by it in their choice of the localities in which they desire to live!

And yet here and there the agricultural practice of more or less extended districts, if not really founded upon or directed by, is yet to be explained only by principles such as those I have above illustrated. I shall mention only one example. The chalk in Yorkshire, in Suffolk, and in other southern counties, consists of a vast number of beds, which, taken all together, form a deposit of very great thickness. Now, the upper beds of the chalk form poor, thin, dry soils, producing a scanty herbage, and only under the most skilful

* See page 94.

culture yielding profitable crops of corn. The lower beds, on the contrary, are marly; produce a more stiff, tenacious, and even fertile soil; and are found in a remarkable degree to enrich the soils of the upper chalk, when laid on as a top-dressing in autumn, and allowed to crumble under the action of the winter's frost. Hence in Yorkshire, Wiltshire, Hampshire, and Kent, where the lower chalk covers the surface, or is found at no great depth beneath it, it is dug out of the sides of the hills, or pits are sunk for it, and it is immediately laid upon the land with great benefit to the soil. But in parts of Suffolk, where the soil equally rests upon the upper chalk, there is no other chalk in the neighbourhood, or to be met with at any reasonable depth, which will materially improve the land. The farmers find it, from long experience, to be more economical to bring chalk by sea from Kent to lay on their lands in Suffolk, than to cover them with any portion of the same material from their own farms. The following imaginary section will fully explain the fact here mentioned:—

No. 3.



In this diagram 1 represents the London clay; 2, the plastic clay which is below it; 3, the upper chalk with flints, rising to the surface in Suffolk; and 4, the lower chalk, without flints, which is too deep to be reached in Suffolk, but which rises to the surface in Kent,—where it is abundant, is easily accessible, and whence it is transmitted across the estuary of the Thames into Suffolk.

3. The further fact that the several stratified rocks are remarkably constant in their mineral character, renders this knowledge of the order of relative superposition still more valuable to the agriculturist. Thousands of different beds are known to geologists to occur on various parts of the earth's surface—each occupying its own unvarying place in the series. Most of these beds also, when they crumble or are worn down, produce soils possessed of some peculiarity by which their general agricultural capabilities are more or less affected,—and these peculiarities may generally be observed in soils formed from rocks of the same age—that is, occupying the same place in the series—in whatever part of the world we find them. Hence if the agricultural geologist be informed that his friend has bought, or is in treaty for a farm or an estate, and that it is situated upon such and such a rock, or geological for-

mation, he can immediately give a very probable opinion in regard to the agricultural value of the soil, whether the property be in England, in Australia, or in New Zealand. If he knows the nature of the climate also, he will be able to estimate with tolerable correctness how far the soil is likely to repay the labours of the practical farmer,—nay, even whether it is likely to suit better for arable land or for pasture, and if for arable, what species of white crops it may be expected to produce most abundantly.

These facts are so very curious, and illustrate so beautifully the value of geological knowledge —if not to A and B, the holders or proprietors of this and that small farm, yet to enlightened agriculturists,—to scientific agriculture in general,— that I shall explain this part of the subject more fully in a separate section. To those who are now embarking in such numbers in quest of new homes in our numerous colonies, who hope to find, if not a more willing, at least a more attainable soil in new countries, no kind of agricultural knowledge can at the outset,—I may say, even through life,— be so valuable as that to which the rudiments of geology will lead them. Those who prepare themselves the best for becoming farmers or proprietors in Canada, in New Zealand, or in wide

Australia, yet leave their native land in general without a particle of that preliminary *practical* knowledge, which would qualify them to say, when they reach the land of their adoption, "On this spot, rather than that,—in this district, rather than that,—will I purchase my allotment, because, though both appear equally inviting, yet I know from the geological structure of the country, that here I shall have the more permanently productive soil; here I am more within reach of the means of agricultural improvement; here, in addition to the riches of the surface, my descendants may hope to derive the means of wealth from mineral riches beneath." And this oversight has arisen chiefly from the value of such knowledge not being understood—often from the very nature of it being unknown, even to otherwise well instructed practical men. It is not to men well skilled merely in the details of local farming, and who are therefore deservedly considered as authorities and good teachers in regard to local or district practice, that we are to look for an exposition, often not even for a correct appreciation, of those general principles on which a universal system of agriculture must be based—without which principles, indeed, it must ever remain a mere collection of empirical rules, to be studied and laboriously mastered in every new district we go to—as the traveller in foreign lands must acquire a new language every successive frontier he passes. England, the mistress of so many wide and unpeopled lands, over which the dwellings of her adventurous sons are hereafter to be scattered, on which their toil is to be expended, and the glory of their motherland by their exertions to be perpetuated—England should especially encourage all such learning, and the sons of English farmers willingly avail themselves of every opportunity of acquiring it.

SECTION IV.—OF GEOLOGICAL FORMATIONS, AND THE GENERAL CHARACTERS OF THE SOILS THAT REST UPON THEM.

The thousands of beds or strata of which I have spoken as lying one over the other in the crust of the globe, have, partly for convenience, and partly in consequence of certain remarkably distinctive characters observed among them, been separated by geologists into three great divisions—the *primary*, which are the lowest and the oldest; the *secondary*, which lie over them; and the *tertiary*, which are uppermost, and have been most recently formed. The strata, in these several divisions, have again been subdivided into groups, called *formations*. The following table exhibits the names and thicknesses of these formations, and the mineralogical characters of the rocks of which they severally consist.

I. TERTIARY STRATA.

1. The *London and Plastic clays*, 500 to 900 feet thick, consist of stiff, almost impervious, dark coloured clays,—chiefly in pasture. The lower beds are mixed with sand, and produce an arable soil, but extensive heaths and wastes rest upon them in Berkshire, Hampshire, and Dorset.

II. SECONDARY STRATA.

2. *The Chalk*, about 600 feet in thickness, consists in the upper part (see diagram, No. 3, p. 88) of a purer chalk with layers of flint; in the lower, of a marly chalk without flints. The soil of the upper chalk is chiefly in sheep-walks, that of the lower chalk is very productive of corn.

3. The *Green Sand*, 500 feet thick, consists of 150 feet of clay, with about 100 feet of sand above, and 250 feet below it. The upper sand forms a very productive arable soil, and the clay imper-

vious, wet and cold lands chiefly in pasture. The lower sand is generally unproductive.

It is an important agricultural remark, that where the clay (plastic clay) comes in contact with the top of the chalk, an improved soil is produced, and that where the chalk and the green sand mix, extremely fertile patches of country present themselves. (See pages 86 and 87.)

4. The *Wealden formation*, nearly 1000 feet thick, consists of 400 feet of sand, covered by 300 of clay, and resting upon 250 of marls and limestones. The clay forms the poor wet pastures of Sussex and Kent. On the sands below the clay rest heaths and brushwood; but where the marls and limestones come to the surface, the land is of better quality, and is susceptible of profitable arable culture.

5. In the *Upper Oolite*, of 600 feet in thickness, we have a bed of clay (Kimmeridge clay) 500 feet thick, covered by 100 feet of sandy limestones. The clay lands are difficult and expensive to work, and are chiefly in old pasture. The sandy limestone soils above the clay are also poor, but where they rest immediately upon, and are intermixed with the clay, excellent arable land is produced.

6. The *Middle Oolite* of 500 feet consists also of

a clay (Oxford clay) dark-blue, adhesive, and nearly 1000 feet thick, covered by 100 feet of limestones and sandstones. These latter produce good arable land where the lime happens to abound; the clays form close heavy compact soils, most difficult and expensive to work. The extensive pasture lands of Bedford, Huntingdon, Northampton, Lincoln, Wilts, Oxford, and Gloucester, rest chiefly upon this clay, as do also the fenny tracts of Lincoln and Cambridge.

7. The *Lower or Bath Oolite*, of 500 feet in thickness, consists of many beds of limestone and sandstone, with about 200 feet of clay in the centre of the formation. The soils are very various in quality, according as the sandstone or limestone predominates. The clays are chiefly in pasture,—the rest is more or less productive, easily worked, arable land. In Gloucester, Northampton, Oxford, the east of Leicester, and in Yorkshire, this formation is found to lie immediately beneath the surface, and a little patch of it occurs also on the south-eastern coast of Sutherland.

6. The *Lias* is an immense deposit of blue clay from 500 to 1000 feet in thickness, which produces cold, blue, unproductive, clay soils. It forms a long stripe of land from the mouth of the Tees,

in Yorkshire, to Lyme Regis in Dorset. It is chiefly in old, and often very valuable pasture.

9. The *New Red Sandstone*, though only 500 feet in thickness, forms the surface of nearly the whole central plain of England, and stretches north through Cheshire to Carlisle and Dumfries. It consists of red sandstones and marls,—the soils on which are easily and cheaply worked, and form some of the richest and most productive arable lands in the island. In whatever part of the world the red soils of this formation have been met with, they have been found to possess in general the same agricultural capabilities.

10. The *Magnesian Limestone*, from 100 to 500 feet in thickness, forms a stripe of generally poor thin soil from Durham to Nottingham, capable of improvement as arable land by high farming, but bearing naturally a poor pasture, intermingled with sometimes magnificent furze.

11. The *Coal Measures*, from 300 to 3000 feet thick, consist of beds of sandstones and dark blue shales (hard clays), intermingled (*interstratified*) with beds of coal. Where the sands come to the surface, the soil is thin, poor, hungry, sometimes almost worthless. The shales, on the other hand, produce stiff, wet, almost unmanageable clays;—not unworkable, yet expensive to

work, and requiring draining, lime, skill, capital, and a zeal for improvement, to be applied to them, before they can be made to yield the remunerating crops of corn they are capable of producing.

12. To the *Millstone Grits* of 600 feet or upwards in thickness the same remarks apply. They are often only a repetition of the sandstones and shales of the coal measures, forming in many cases soils still more worthless. When the sandstones prevail, large tracts lie naked, or bear a thin and stunted heath; where the shales abound, the naturally difficult soils of the coal shales again recur. These rocks are generally found on the outskirts of our coal-fields.

13. The *Mountain Limestone*, 800 to 1000 feet thick, is a hard blue limestone rock, separated here and there into distinct beds by layers of sandstones, of sandy slates, or of blue shales like those of the coal measures. The soil upon the limestone is generally thin, but produces a naturally sweet herbage. When the limestone and clay (shale) adjoin each other, arable land occurs, which is naturally productive of oats, yet, when the climate is favourable, capable of being converted into good wheat land. In the north of England a considerable tract of country is covered by these

rocks, but in Ireland they form nearly the whole of the interior of the island.

14. The *Old Red Sandstone* varies in thickness from 500 to 10,000 feet. It possesses many of the valuable agricultural qualities of the *new red*, consisting, like it, of red sandstones and marls, which crumble down into rich red soils. Such are the soils of Brecknock, Hereford, and part of Monmouth; of part of Berwick and Roxburgh; of Haddington and Lanark; of southern Perth; of either shore of the Moray Firth; and of the county of Sutherland. In Ireland, also, these rocks abound in Tyrone, Fermanagh, and Monaghan; in Waterford, in Mayo, and in Tipperary. In all these places, the soils they form are generally the best in their several neighbourhoods, though here and there,—where the sandstones are harder, more siliceous and impervious to water,—tracts, sometimes extensive, of heath and bog occur.

III.—PRIMARY STRATA.

15. *The Upper Silurian system* is nearly 4000 feet in thickness, and forms the soils over the lower border counties of Wales. It consists of sandstones and shales, with occasional limestones;

but the soils formed from these beds take their character from the general abundance of clay. They are cold, usually unmanageable, *muddy* clays, with the remarkably inferior agricultural value of which the traveller is immediately struck, as he passes westward off the red sandstones of Hereford on to the upper silurian rocks of Radnor.

16. The *Lower Silurian* rocks are also nearly 4000 feet in thickness, and in Wales lie to the west of the upper silurian rocks. They consist of about 2500 feet of sandstone, on which, when the surface is not naked, barren heaths alone rest.

Beneath these sandstones lie 1200 feet of sandy and earthy limestones, from the decay of which, as may be seen on the southern edge of Caermarthen, fertile arable lands are produced.

17. The *Cambrian System*, of many thousand yards in thickness, consists in great part of clay slates, more or less hard, which often weather slowly, and almost always produce either poor and thin soils, or cold, difficultly manageable clays, expensive to work, and requiring *high farming* to bring them into profitable arable cultivation. Cornwall, western Wales, and the mountains of Cumberland, in England; the high country which stretches from the Lammermuir hills to Portpatrick, in Scotland; the mountains of

Tipperary, and a large tract on the extreme south of Ireland,—on its east coast, and far inland from the bay of Dundalk,—are covered by these slate rocks. Patches of rich, well cultivated land occur here and there on this formation, with much also that is improvable; but the greater part of it is usurped by worthless heath and extensive bogs.

18. The *Mica Slate and Gneiss systems* are of unknown thickness, and consist chiefly of hard and slaty rocks, crumbling slowly, forming poor, thin soils, which rest on an impervious rock, and which, from the height to which this formation generally rises, are rendered more unproductive by an unpropitious climate. They form extensive heathy tracts in Perth and Argyle, and on the north and west of Ireland. Here and there only, in the valleys or sheltered slopes, and by the margins of the lakes, spots of bright green meet the eye, and patches of a willing soil, fertile in corn.

A careful perusal of the preceding sketch of the general agricultural capabilities of the soils formed from the several classes of stratified rocks, will have presented to the reader many illustrations of the facts stated in the preceding section; he will have drawn for himself—to specify a few examples—the following among other conclusions.

1. That some formations, like the new red sandstone, yield a soil almost always productive; others, as the coal measures and millstone grits, a soil almost always *naturally* unproductive.

2. That good, or better land at least, than generally prevails in a district, may be expected where two formations or two different kinds of rock meet,—as when a limestone and a clay mingle their mutual ruins for the formation of a common soil.

3. That in almost every country extensive tracts of land on certain formations will be found laid down to natural grass, *in consequence of the original difficulty and expense of working.* Such are the Lias, the Oxford, the Kimmeridge, and the London clays. In raising corn, it is natural that the lands which are easiest and cheapest worked should be first subjected to the plough; it is not till implements are improved, skill increased, capital accumulated, and population presses, that the heavier lands will be rescued from perennial grass, and made to produce that greatly increased amount of food for both man and beast, which they are easily capable of yielding.

The turnip soils of Great Britain are in many districts, it may be, but indifferently farmed; and the state has reason to complain of much individual neglect of known and certain methods of increasing their productiveness; but the next *great* achievement which British agriculture has to effect, is to subdue the stubborn clays, and to convert them into what many of them are yet destined to become, the richest corn-bearing lands in the kingdom.

CHAPTER VII.

Soils of the Granitic and Trap Rocks—Accumulations of transported Sands, Gravels, and Clays.—Use of Geological Maps in reference to Agriculture.—Physical characters and Chemical constitution of Soils.—Relation between the nature of the Soil and the kind of Plants that naturally grow upon it.

It was stated, in the preceding lecture, (see p. 82,) that rocks are divided by geologists into the stratified and the *unstratified*.* The stratified rocks cover by far the largest portion of the globe, and thus form a variety of soils, of which a general description has just been given. The unstratified rocks are of two kinds—the *granites* and the *trap*

* The unstratified are often called *crystalline* rocks, because they frequently have a glassy appearance, or contain regular crystals of certain mineral substances; often also *igneous* rocks, because they appear all to have been originally in a melted state, or to have been produced by fire.

rocks; and as a considerable portion of the area of our island is covered by them, it will be proper shortly to consider the peculiar characters of each, and the differences of the soils produced from them.

SECTION I.—SOILS OF THE GRANITES AND TRAP ROCKS.

1. The *granites* consist of a mixture, in different proportions, of three minerals, known by the names of *quartz*, *felspar*, and *mica*. The latter, however, is generally present in such small quantity, that in our general description it may be safely left out of view. Granites, therefore, consist chiefly of quartz and felspar, in proportions which vary very much, but the former, on an average, constitutes perhaps from one-third to one-half of the whole.

Quartz has already been described—(see p. 51)—as the substance of flint, the silica of the chemist. When the granite decays, this portion of it forms a more or less coarse siliceous sand.

Felspar is a white, greenish, or flesh-coloured mineral, often more or less earthy in its appearance, but generally hard and brittle, and sometimes glassy. It is scratched by, and thus is readily distinguished from, quartz. When it decays, it forms an exceedingly fine clay.

to follow page 116

how much *bottom* heat forces the growth, especially of young plants; and wherever a natural warmth exists in the soil, independent of the sun, as in the neighbourhood of volcanoes, there it exhibits the most exuberant fertility. One main influence of the sun in spring and summer is dependent upon its power of thus warming the soil around the young roots, and thus rendering it propitious to their rapid growth. But the sun does not warm all soils alike: some become much hotter than others, though exposed to the same sunshine. When the temperature of the air in the shade is no higher than 60° to 70°, a *dry* soil may become so warm as to raise the thermometer to 90° or 100°. Mrs. Ellis states, that among the Pyrenees the rocks actually smoke after rain under the influence of the summer sun, and become so hot, that you cannot sit down upon them. In *wet* soils the temperature rises more slowly, and never attains the same height as in a dry soil by 10° or 15°. Hence it is strictly correct to say, that wet soils are *cold;* and it is easy to understand how this coldness is removed by perfect drainage. Dry sands and clays, and blackish garden mould, become warmed to nearly an equal degree under the same sun; brownish red soils are heated somewhat more, and dark-coloured peat the most of weather, to a more or less fine powder, affording materials for a soil; in the granites the felspar is the principal source of all the earthy matter they are capable of yielding. If we compare together, therefore, the chemical composition of the two minerals (hornblende and felspar), we shall see in what respect these two varieties of soil ought to differ. Thus they consist of

	Felspar.	Hornblende.
Silica,	65	42
Alumina,	18	14
Potash and soda,	17	trace.
Lime,	trace	12
Magnesia,	do.	14
Oxide of iron,	do.	$14\frac{1}{2}$
Oxide of manganese,	do.	$\frac{1}{2}$
	100	97

A remarkable difference appears thus to exist, in chemical constitution, between these two minerals—a difference which must affect also the soils produced from them. A granite soil, in addition to the siliceous sand, will consist chiefly of silica, alumina, and potash; a hornblende soil, in addition to silica and alumina, of much lime, magnesia, and oxide of iron—of nearly $2\frac{1}{2}$ cwt. of each of these latter for every ton of decayed rock. A hornblende soil, therefore, contains more of those inorganic constituents which the plants require for their healthy sustenance, and therefore will prove more generally productive than a soil of decayed felspar. But when the two are mixed, as in the greenstones, the soil must be still more favourable to vegetable life. The potash and soda, of which the hornblende is nearly destitute, the felspar is able abundantly to supply; while, by the hornblende are yielded lime and magnesia, which are known to exercise a remarkable influence on the progress of vegetation.

Thus theory shews, that while granite soils may be eminently unfruitful, trap soils may be eminently fertile. And such is actually the result of observation and experience in every part of the globe. Unproductive granite soils cover nearly the whole of Scotland north of the Grampians, and large tracts of land in Devon and Cornwall, and on the east and west of Ireland; while fertile trap soils extend over thousands of square miles in the lowlands of Scotland, and in the north of Ireland; and where in Cornwall they occasionally mix with the granite soils, they are found to redeem them from their natural barrenness.

While such is the general rule in regard to these two classes of soils, it happens on some spots that the presence of other minerals in the granites, or of hornblende or mica in larger quantity than usual, give rise to a granitic soil of average fertility, as is the case in the Scilly isles; while, in like manner, the trap rocks are sometimes, as in parts of the isle of Skye, so peculiar in constitution as to condemn the land to almost hopeless infertility.

In some districts the decayed traps are dug up, and applied with advantage, as a top-dressing, to other kinds of land; and as by admixture with the decayed trap, the granitic soils are known to be improved in quality, so an admixture of decayed granite with many trap soils, were it readily accessible, might add to their fertility also.

SECTION II.—OF THE SUPERFICIAL ACCUMULATIONS OF TRANSPORTED MATERIALS ON DIFFERENT PARTS OF THE EARTH'S SURFACE

It is necessary to guard the reader against disappointment, when he proceeds to examine the existing relation between the soils and the rocks on which they lie, or to infer the quality of the soil from the known nature of the rock in conformity with what has been above laid down,—by explaining another class of geological appearances which present themselves not only in our own country but in almost every other part of the globe.

The unlearned reader of the preceding section and chapter may say—I know excellent land resting upon the granites, fine turnip soils on the Oxford or London clays, tracts of fertile fields on the coal measures, and poor, gravelly farms on the boasted new red sandstone: I have no faith in theory—I can have none in theories which are so obviously contradicted by natural appearances. Such, it is to be feared, is the hasty mode of reasoning among too many *locally** excellent practical men, familiar, it may be, with many useful and important facts, but untaught to look through and beyond isolated facts to the principles on which they depend.

Every one who has lived long, on the more exposed shores of our island, has seen, that when the weather is dry, and the sea winds blow strong, the sands of the beach are carried inland and spread over the soil, sometimes to a considerable

* By *locally* excellent, I mean those who are the best possible farmers of their own district and after their own way, but who would fail in other districts requiring other methods. To the possessor of agricultural principles the modifications required by difference of crop, soil, and climate, readily suggest themselves, where the mere practical man is bewildered, disheartened, and in despair.

distance from the coast. In some countries this sand-drift takes place to a very great extent, and gradually swallows up large tracts of fertile land.

Again, most people are familiar with the fact, that during periods of long continued rain, when the rivers are flooded and overflow their banks, they not unfrequently bear with them loads of sand and gravel, which they carry far and wide, and strew at intervals over the surface soil.

So the annual overflowings of the Nile, the Ganges, and the river of Amazons, gradually deposit accumulations of soil over surfaces of great extent;—and so also the bottoms of most lakes are covered with thick beds of sand, gravel, and clay, which have been conveyed into them from the higher grounds by the rivers through which they are fed.

To these and similar agencies, a large portion of the existing dry land of the globe has been, and is still exposed. Hence in many places, the rocks, and the soils naturally derived from them, are buried beneath accumulated heaps or layers of sand, gravel, and clay, which have been brought from a greater or less distance, and which have not unfrequently been derived from rocks of a totally different kind from those of the district in which they are now found. On these accumulations of transported materials, a soil is produced which often has no relation in its characters to the rocks which cover the country, and the nature of which a familiar acquaintance with these rocks would not enable us to predict.

To this cause is due that discordance between the first indications of geology, as to the origin of soils from the rocks on which they rest, and the actually observed character of those soils in certain districts—of which discordance mention has been made as likely to awaken doubt and distrust in the mind of the less instructed student in regard to the predictions of agricultural geology. There are several circumstances, however, by which the careful observer is materially aided in endeavouring to understand what the nature of the soils is likely to be, and how they ought to be treated, even when the subjacent rocks are thus overlaid by masses of drifted materials. Thus—

1. It not unfrequently happens, that the materials brought from a distance are more or less mixed up with the fragments and decayed matter of the rocks which are native to the spot, so that though modified in quality, the soil, nevertheless, retains the general characters of that which is formed on other spots from the decay of these rocks alone.

2. Where the formation is extensive, or covers a large area, as the new red sandstones and coal measures do in this country,—the mountain limestones in Ireland, and the granites in the north of Scotland—the transported sand, gravel, or clay, strewed over one part of the formation, has not unfrequently been derived from the rocks of another part of the *same* formation, so that, after all, the soils may be said to be produced from the rocks on which they rest, and may be judged of from the known constitution of these rocks.

3. Or if not from the rocks of the same formation, they have most frequently been derived from those of a neighbouring formation—from rocks which are to be found at *no great distance*, and generally on higher ground. Thus the ruins of the mill-stone grit rocks are often spread over the surface of the coal measures—of these, again, over the magnesian limestone,—of the latter, over the new red sandstone, and so on. The effect of this kind of transport upon the soils, is merely to overlap, as it were, the edges of one formation with the proper soils of the formations that adjoin it in the particular direction from which the drifted materials are known to have come.

It appears, therefore, that the occurrence on certain spots, or tracts of country, of soils that have no apparent relation to the rocks on which they immediately rest, tends in no way to throw doubt upon, to discredit or to disprove, the conclusions drawn from the more general facts and principles of geology. It is still generally true that soils *are* derived from the rocks on which they rest. The exceptions are local, and the difficulties which these local exceptions present, require only from the agricultural geologist a more careful study of the structure of each district, before he pronounces a dicided opinion as to the degree of fertility it either naturally possesses, or by skilful cultivation may be made to attain.

Geological *maps* point out with more or less precision the extent of country over which the chalk, the red sandstone, the granites, &c., are found immediately beneath the loose materials on the surface; and these maps are of great value in indicating also the general quality of the soils over the same districts. It may be true, that here and there the *natural* soils are masked or buried by transported materials, yet the *political economist* may, nevertheless, with safety estimate the general agricultural capabilities and resources of a country by the study of its geological structure—the *capitalist* judge in what part of it he is likely to meet with an agreeable investment—and the *practical* *farmer* in what country he may expect to find land that will best reward his labours—that will admit of the kind of culture to which he is most accustomed, or, by the application of better methods, will manifest the greatest agricultural improvement.

SECTION III.—OF THE PHYSICAL CHARACTERS OF SOILS.

The influence of climate on the fertility of a soil is often very great. This influence depends very much upon what are called the *physical* properties of soils.

1. Some soils are heavier and denser than others, sand and marls being the heaviest, and peaty soils the lightest. In reclaiming peat lands, it is found to be highly beneficial to increase their density by a covering of clay, sand, or limestone gravel.

2. Again, some soils absorb the rains that fall, and retain them in larger quantity and for a longer period than others. Strong clays absorb and retain nearly three times as much water as sandy soils do, while peaty soils absorb a still larger proportion. Hence the more frequent necessity for draining clayey than sandy soils; hence also the reason why, in peaty lands, the drains must be kept carefully open, in order that the access of

springs and of other water from beneath, may be as much as possible prevented.

3. When dry weather comes, soils lose water by evaporation with different degrees of rapidity. In this way a siliceous sand will give off the same weight of water in the form of vapour, in one third of the time necessary to evaporate it from a stiff clay, a peat, or a rich garden mould, when all are equally exposed to the air. Hence the reason why plants are so soon burned up in a sandy soil. Not only do such soils *retain* less of the rain that falls, but that which is retained is also more speedily dissipated by evaporation. When rains abound, however, or in very moist seasons, these same properties of sandy soils enable them to sustain a luxuriant vegetation, when plants will perish on clay lands from excess of moisture.

4. In drying under the influence of the sun, soils contract and diminish in bulk in proportion to the quantity of clay or of peaty matter they contain. Sand does not at all diminish in bulk in drying, but peat shrinks in one-fifth, and agricultural clay nearly as much. The roots are thus compressed, and air is excluded, especially from the hardened clays, and thus the plant is placed in a condition unfavourable to its growth. Hence the value of proper admixtures of sand and clay. By the lat-

ter (the clay), a sufficient quantity of moisture is retained, and for a sufficient length of time; while, by the former, the roots are preserved from compression, and a free access of air is permitted.

5. In the hottest and most drying weather, the soil has seasons of respite from the scorching influence of the sun. During the cooler season of the night, even when no perceptible dew falls, it has the power of again extracting from the air a portion of the moisture it had lost during the day. Perfectly pure sand possesses this power in the least degree; it absorbs little or no moisture from the air. A stiff clay, on the other hand, will in a single night absorb sometimes as much as a 30th part of its own weight, and a dry peat as much as a 12th of its weight; and, generally, the quantity thus drunk in by soils of various qualities, is dependent upon the proportions of clay and vegetable matter they severally contain. We cannot fail to perceive from these facts, how much of the productive capabilities of a soil is dependent upon the proportions in which its different earthy and vegetable constituents are mixed together.

6. The temperature of a soil, or the degree of warmth it is capable of attaining under the influence of the sun's rays, materially affects the progress of vegetation. Every gardener knows

next read p. 105.

to follow p 104

Granite generally forms hills and sometimes entire ridges of mountains. When it decays, the rains and streams wash out and carry down the fine felspar clay, and leave the (quartz) sand on the sides of the hills. Hence the soil in the bottoms and flats of granite countries consists of a cold, stiff, wet, more or less impervious clay, which often bears only heath, bog, or a poor and unnutritive pasture. The hill sides are either bare or covered with a thin, sandy, and ungrateful soil, of which little can be made by the aid even of skill and industry. Yet the opposite sides of the same mountains often present a remarkable difference in this respect, those which are most beaten by the rains having the light clay most thoroughly washed from their surfaces, and being therefore the most barren.

2. The *trap* rocks, comprising the greenstones and basalts, consist essentially* of felspar and *hornblende* or *augite*. In contrasting the trap rocks with the granites, it may be stated *generally*, that while the granites consist of felspar and *quartz*, the traps consist of felspar and hornblende (or augite). In the traps, both the felspar and the hornblende are reduced, by the action of the

* The reader is referred for more *precise* information to the author's "LECTURES," pp. 377 to 390.

all. It is probable, therefore, that the presence of dark-coloured vegetable matter renders the soil more absorbent of heat from the sun, while the colour of the dark-red marls of the new and old red sandstones may, in some degree, aid the other causes of fertility in the soils which they produce.

In reading the above observations, the practical reader can hardly fail to have been struck with the remarkable similarity in physical properties between stiff clay and peaty soils. Both retain much of the water that falls in rain, and both part with it slowly by evaporation. Both contract much in drying; and both absorb moisture readily from the air in the absence of the sun. In this similarity of properties, we see not only why the first steps in improving both kinds of soil must be very nearly the same; but why, also, a mixture either of clay or of vegetable matter will equally impart to a sandy soil many of those aids to, or elements of, fertility—of which they are alike possessed.

SECTION IV.—OF THE CHEMICAL CONSTITUTION OF SOILS.

Soils perform at least three functions, in reference to vegetation. They serve as a basis in which plants may fix their roots and sustain themselves in their erect position,—they supply inorganic food to vegetables at every period of their growth,—and they are the medium in which many chemical changes take place, that are essential to a right preparation of the various kinds of food which the soil is destined to yield to the growing plant.

We have spoken of soils as consisting chiefly of sand, lime, and clay, with certain saline and organic substances in smaller and variable proportions. But the study of the ash of plants (see chap. iv.) shews us, that a fertile soil must of necessity contain an appreciable quantity of at least eleven different substances, which in most cases exist in greater or less relative abundance in the ash both of wild and of cultivated plants.

Two well known geological facts lead to precisely the same conclusion. We have seen that the soils formed from the unstratified rocks,—the granites and the traps,—while they each contain certain earthy substances in proportions peculiar to themselves, yet contain also in general a *trace* of most of those different kinds of matter which are found in the ash of plants. And when to this fact is added the other, that the stratified rocks appear to be only the long accumulating fragments and ruins of more ancient unstratified masses—which, under various agencies, have gradually crumbled to dust, been strewed over the surface in alternate layers, and afterwards again consolidated,—the reader will readily grant, that in all rocks, and consequently in all soils, *traces* of every one of these substances may generally be presumed to exist.

Actual *chemical analysis* confirms these deductions in regard to the constitution of soils. It shews that, in most soils, the presence of the several constituents of the ash of plants may be detected, though in very variable proportions. And following up its investigations, in regard to the effect of this difference in the proportion of the generally less abundant constituents of the soil, it establishes certain other points of the greatest possible importance to agricultural practice. Thus, it has found, for example,

1. That as a proper adjustment of the proportions of clay and sand is necessary, in order that a soil may possess the most favourable *physical* properties—so that the mere presence of the various kinds of inorganic food in a soil is not sufficient to make it productive of a given crop, but that they must be so adjusted in quantity that

the plant shall be able readily and at the proper time to obtain an adequate supply of each.

2. That when a soil is particularly poor in certain of these substances, the valuable, cultivated corn crops, grasses, and trees, refuse to grow upon them in a healthy manner, and to yield remunerating returns. And,

3. That when certain other substances are present in too great abundance, the soil is rendered equally unpropitious to the most important crops.

In these facts the intelligent reader will perceive the foundation of the varied applications to the soil which are everywhere made under the direction of a skilful practice, and of the difficulties which, in so many localities, lie in the way of bringing the land into such a state as shall fit it readily to supply all the wants of those kinds of vegetables which it is the special object of artificial culture easily and abundantly to raise.

Chemical analysis is a difficult art,—one which demands much chemical knowledge, and skill in chemical practice (manipulation, as it is called), and calls for both time and perseverance—if valuable, trustworthy, and *minutely correct* results are to be obtained. I believe it is only by aiming after such minutely correct results that chemical analysis is likely to throw light on the peculiar properties of those soils which, while they possess much general similarity in composition and in physical properties, are yet found in practice to possess very different agricultural capabilities. Many such cases occur in every country, and they are the kind of difficulties in regard to which agriculture has a right to say to chemistry—"These are matters which I hope and expect you will satisfactorily clear up." But while agriculture has a right to use such language, she has herself preliminary duties to perform. She has no right in one breath to deny the value of chemical theory to agricultural practice, and in another to ask the sacrifice of time and labour in doing her chemical work. Chemistry is a wide field, and many zealous lives may be spent in the prosecution of it without at all entering upon the domain of practical agriculture. It may be that here and there it may fall in with the humour or natural bias of some one chemist to apply his knowledge to this most important art; but hitherto the appreciation of such efforts has, in general, been so small—the reception of scientific results and suggestions by the agricultural body so ungracious—that little wonder can exist that so many have quitted the field in disgust—that the majority of capable men should studiously avoid it.

Hence it has happened that, in England, the analysis of soils has rarely been undertaken, except as a matter of professional business, where so much time was, by a fair calculation, given for so much money, and an analysis made, of that degree of accuracy only which the time allotted to it permitted the analyst to attain.

In order, therefore, to illustrate the deductions which, as above stated, may be drawn from an accurate chemical analysis, I shall exhibit the constitution of three different soils as determined by Sprengel, a German chemist, now at the head of the Prussian Agricultural school, and whose own taste, as well as his professional function, have long directed his attention, and with much success, to scientific agriculture.

No. 1 is a very fertile alluvial soil from East Friesland, formerly overflowed by the sea, but for 60 years cultivated with corn and pulse crops *without manure.*

No. 2 is a fertile soil near Göttingen, which produces excellent crops of clover, pulse, rape, potatoes, and turnips, the two last more especially *when manured with gypsum.*

No. 3 is a very barren soil from Lunenburg.

When washed with water in the manner described in pages 70 to 73, they gave, respectively, from 1000 parts of soil—

	No. 1.	No. 2.	No. 3.
Soluble saline matter,	18	1	1
Fine earthy and organic matter (clay),	937	839	599
Siliceous sand,	45	160	400
	1000	1000	1000

The most striking distinction presented by these numbers is the large quantity of saline matter in No. 1. This soluble matter consisted of common salt, chloride of potassium, sulphate of potash and gypsum, with a trace of sulphate of magnesia, sulphate of iron, and phosphate of soda. The presence of this comparatively large quantity of these different saline substances,—originally derived, no doubt, in great part from the sea,—was probably one reason why it could be so long cropped without manure.

The unfruitful soil is much the lightest of the three, containing 40 per cent. of sand; but this is not enough to account for its barrenness—many light soils containing a larger proportion of sand, and yet being sufficiently fertile.

The finer portions separated from the sand, and soluble matter, consisted in 1000 parts of

	No. 1.	No. 2.	No. 3.
Organic matter, . .	97	50	40
Silica, . . .	648	833	778
Alumina, . .	57	51	91
Lime, . . .	59	18	4
Magnesia, . .	8½	8	1
Oxide of iron, . .	61	30	81
Oxide of manganese, .	1	3	½
Potash, . . .	2	trace.	trace.
Soda, . . .	4	do.	do.
Ammonia, . .	trace.	do.	do.
Chlorine, . .	2	do.	do.
Sulphuric acid, . .	2	¾	do.
Phosphoric acid, . .	4½	1¾	do.
Carbonic acid, . .	40	4½	do.
Loss, . . .	14	—	4½
	1000	1000	1000

1. The composition of No. 1 illustrates the first of those general deductions above stated, that a considerable supply of *all* the species of inorganic food is necessary to render a soil eminently fertile. Not only does this soil contain a comparatively large quantity of soluble saline matter, but it contains also nearly 10 per cent. of organic matter, and, what in connection with this is of great importance, 6 per cent. of lime. The potash and soda, and the several acids, are also present in sufficient abundance.

2. In the second,—a fertile soil, but one which *cannot dispense with manure*,—there is little soluble saline matter, and in the insoluble portion we see that there are mere *traces* of potash, soda, and the important acids. It contains also 5 per cent. only of organic matter, and about 2 per cent. of lime, which smaller proportions, together with the deficiencies above stated, remove this soil from the most *naturally* fertile class to that class which is susceptible, in hands of ordinary skill, of being *brought to*, and *kept in*, a very productive condition.

3. In the fine part of the third soil, we observe that there are many more substances deficient than in No. 2. The organic matter amounts apparently to 4 per cent., and there seems to be nearly half a per cent. of lime. But it will be recollected, that this soil contains 40 per cent. of sand, so that in every hundred of soil there are only 60 of the fine matter, of which the composition is presented in the table, or 100 lbs. of the native soil contain only $2\frac{1}{2}$ lbs. of organic matter and $\frac{1}{4}$ lb. of lime.

But all these *wants* would not condemn the soil to hopeless barrenness, because in favourable circumstances, and where it was worth the cost, they might all be supplied. But the oxide of iron amounts to 8 per cent. of this fine matter, a proportion of this substance which, in a soil containing so little organic matter, appears, from practical experience, to be incompatible with the healthy growth of cultivated crops. To this soil, therefore, there requires to be added not only those substances of which it is destitute, but such other substances also as shall prevent the injurious effect of the large proportion of oxide of iron.

In these three soils, then, we have examples, *first*, of one which contains within itself all the elements of fertility; *second*, of a soil which is destitute, or nearly so, of certain substances,—which, however, can be readily added by the ordinary manures in general use,—and to which the elements of gypsum are especially useful, in aiding it to feed the potato and the turnip; and, *third*, of a soil not only poor in many of the necessary species of the inorganic food of plants, but too rich in one which, when present in excess, is prejudicial to vegetable life.

This illustration, therefore, will aid the general reader in comprehending how far rigid chemical analysis is fitted to throw light upon the capabilities of soils, and to *direct* agricultural practice.

SECTION V.—OF THE RELATION THAT EXISTS BETWEEN THE CHARACTER OF THE SOIL AND THE KIND OF PLANTS THAT GROW UPON IT.

The importance of this study of the chemical constitution of soils will, perhaps, be most readily appreciated by a glance at the very different kinds of vegetables which, under the same circumstances, different soils naturally produce.

There are none so little skilled in regard to the capabilities of the soil, as not to be aware that some lands naturally produce abundant herbage or rich crops, while others refuse to yield a nourishing pasture, and are deaf to the often repeated solicitations of the diligent husbandman. There exists, therefore, a universally understood connection between the kind of soil and the kind of plants that naturally grow upon it. It is interesting to observe how close this relation in many cases is.

1. The sands of the sea-shore, and the margins of salt-lakes, are distinguished by their peculiar tribes of salt-loving plants;—the drifted sands more remote from the beach produce their own long waving coarser grass,—while further inland again, other vegetable races appear.

2. Peaty soils laid down to grass, or existing as natural meadows, produce one woolly soft grass

almost exclusively (the *Holcus lanatus*); when limed, again, these same soils become propitious to green crops and produce much straw, but refuse to fill the ear.

3. On the margins of water-courses, in which silica abounds, the mare's-tail (*Equisetum*) springs up in abundance; while, if the stream contain much carbonate of lime, the water-cress appears and lines its sides, and the bottom of its shallow bed, sometimes for many miles from its source.

4. The Cornish heath (*Erica vagans*) shews itself only above the serpentine rocks; the red clover and the vetch delight in the presence of gypsum; and white clover, of alkaline matter in the soil.

5. Then, again, plants seem to alternate with each other on the same soil. Burn down a forest of pines in Sweden, and one of birch takes its place *for a while*. The pines after a time again spring up and ultimately supersede the birch. The same takes place naturally. On the shores of the Rhine are seen ancient forests of oak from two to four centuries old,—gradually giving place to a natural growth of beech; and others where the pine is succeeding to both. In the Palatinate, the ancient oak woods are followed by natural pines; and in the Jura, the Tyrol, and Bohemia, the pine alternates with the beech.

These and other similar differences depend upon the chemical constitution of the soil. The slug may live well, and therefore infest a field almost deficient in lime; the common land snail will abound at the roots of the hedges only where lime is plentiful, and can easily be obtained for the construction of its shell. So it is with plants. Each grows spontaneously where its wants can be most fully and most easily supplied. If they cannot move from place to place like the living animal, yet their seeds can lie dormant, until either the hand of man or the operation of natural causes produces such a change in the constitution of the soil as to fit it for ministering to their most important wants.

And such changes do naturally come over the soil. The oak, after thriving for long generations on a particular spot, gradually sickens; its entire race dies out,—and other races succeed it. The operation of natural causes has gradually removed from the soil that which favoured the oak, and has introduced or given the predominance to those substances which favour the beech or the pine.

In the hands of the farmer the land grows sick of this crop,—it becomes tired of that. These facts are generally indications of a change in the chemical constitution of the soil. This alteration may proceed slowly and for many years, and the same crops may still grow upon it for a succession of rotations. At length the change is too great for the plant to bear; it sickens, yields an unhealthy crop, and becomes ultimately extinct.

The plants we raise for food have similar likes and dislikes with those that are naturally produced. On some kinds of food they thrive,—fed with others, they sicken or die. The soil must therefore be prepared for their special growth.

In an artificial rotation of crops, we only follow nature. One crop extracts from the soil a certain quantity of all the inorganic constituents of plants; but some of these in much larger proportions than others. A second crop carries off in preference a larger quantity of those substances which the former had left; and thus it is clearly seen, both why an abundant manuring may so alter the constitution of the soil, as to enable it to grow almost any crop; and why, at the same time, this soil may in succession yield more abundant crops and in greater number, if the kinds of plant sown and reaped be so varied as to extract from the soil, one after the other, the several different substances which the manure we have originally added is known to contain.

The management and tilling of the soil, in fact, is a branch of practical chemistry, which, like the art of dyeing or of lead smelting, may advance to a certain degree of perfection, without the aid of pure science ; but which can only have its processes explained, and be led on to shorter,—more simple,—more economical,—and more perfect processes, by the aid of scientific principles.

CHAPTER VIII.

Of the Improvement of the Soil—Mechanical and Chemical Methods—Draining—Subsoiling—Ploughing, and Mixing of Soils—Use of Lime, Marl, and Shell-sand—Manures—Vegetable, Animal, and Mineral Manures.

The soil is possessed of certain existing and obvious qualities, and of certain other dormant capabilities; how are these qualities to be improved,—these dormant capabilities to be awakened?

There are two distinct methods by which these ends may be, in some measure, attained,—by the use of *mechanical*, and by the application of *chemical*, means. Mechanical operations produce changes *chiefly* in the physical properties of the soil,—chemical means alter its elementary constitution. Ploughing, draining, mixing, &c. belong to the former class of operations; manuring and irrigation belong to the latter. It will be proper to consider these methods separately.

SECTION I.—OF MECHANICAL METHODS OF IMPROVING THE SOIL.

1. *Draining.*—The first step to be taken, in order to increase the fertility of nearly all the improveable lands of Great Britain, is to drain them. So long as they remain wet, they will continue to be cold. The heat of the sun's rays, which is intended by nature to warm the soil, will be expended in evaporating the water from its surface; and thus the plants will never receive that genial warmth about their roots which so much favours their rapid growth. Where too much water is present in the soil also, that food of the plant which the soil supplies is so much diluted, that either a much greater quantity of fluid must be taken in by the roots,—much more work done,—or the plant will be scantily nourished. The presence of so much water in the stem and leaf keeps down *their* temperature likewise, when the sun-shine appears; an increased evaporation takes place from their surfaces, a lower natural heat, in consequence, prevails in the interior of the plant, and the chemical changes on which its growth depends proceed with less rapidity.

By the removal of the water, the physical properties of the soil also are in a remarkable degree improved. Dry pipe-clay can be easily reduced to a fine powder, but it naturally, and of its own accord, runs together when water is poured upon it. So it is with clays in the field. The soil expands, becomes close and adhesive, and excludes the air from the roots of the growing plant,—the access of which air appears to be almost an essential element in the healthy growth of the most important vegetable productions.

Open an outlet for the water below, and as it trickles away, the air from above will follow it and take its place among the pores of the soil, carrying to every root the salutary influences it is appointed to bear with it wherever it penetrates. When freed from water also, the stiff soil becomes more mellow; and when once stirred up to a considerable depth, more universally porous,—so that air can make its way everywhere, and the roots can find their easy way in every direction. The presence of vegetable matter,—whether existing naturally in a soil thus physically altered, or artificially added to it,—becomes of double value. When drenched with water, this vegetable matter either decomposes very slowly, or produces acid compounds more or less unwholesome to the plant, and even exerts injurious chemical reactions upon the earthy and saline constituents of the soil. In the presence of air, on the contrary, this vegetable matter decomposes rapidly, produces carbonic acid in large quantity, as well as other compounds fit for food, and even renders the inorganic constituents of the soil more fitted to enter the roots, and thus to supply more rapidly what the several parts of the plant require.

Nor is it only stiff and clayey soils to which draining can with advantage be applied. It will be obvious to every one, that when springs rise to the surface in sandy soils, a drain must be made to carry off the water,—it will also readily occur, that where a sandy soil rests upon a hard or clayey bottom, drains may also be necessary; but it is not unfrequently supposed, that when the subsoil is sand or gravel, that drains can only in special cases be necessary.

Every one, however, is familiar with the fact, that when water is applied to the bottom of a flower-pot full of soil, it will gradually find its way to the surface, however light the soil may be. So it is in sandy soils or subsoils in the open field. If water abound at the depth of a few feet, or if it so abound at certain seasons of the year, *that* water will rise to the surface; and as the sun's heat dries it off by evaporation, more water will follow to supply its place. This attraction from beneath will always go on when the air is dry and warm, and thus a double evil will ensue—the soil will be kept moist and cold, and instead of a constant circulation of air downwards, there will be a constant current of water upwards. Thus will the roots, the under soil, and the organic matter it contains, be all deprived of the benefits which the access of the air is fitted to confer. The remedy for these evils is to be found in an efficient system of drainage.

On this subject I shall add one important practical remark, which will readily suggest itself to the geologist who has studied the action of air and water on the various clay beds that occur here and there as members of the series of stratified rocks. *There are no clays which do not gradually soften under the united influence of air and of running water. It is false economy, therefore, to lay down tiles without soles*—however hard and stiff the clay subsoil may appear to be. In the course of ten or fifteen years the stiffest clays will soften, so as to allow the tile to sink; and many very much sooner. The passage for the water is thus gradually narrowed; and when the tile has sunk a couple of inches, the whole must be taken up. Thousands of miles of drains have been thus laid down, both in the low country of Scotland and in the southern counties of England, which have now become nearly useless; and yet the system still goes on. It would appear even as if the farmers and proprietors of each district—unwilling to believe in or to be benefitted by the experience of others—were determined to prove the matter in their own case also, before they will consent to adopt that surer system which, though demanding a slightly greater outlay at first, will return upon the drainer with no after-calls for either time or capital. If my reader live in a district where this practice is now exploded, and if he be inclined to doubt if other counties be farther behind the advance of knowledge than his own, I would invite him to spend a week in crossing the county of Durham, where he may find opportunities not only of satisfying his own doubts, but of scattering here and there a few words of useful advice among the more intelligent of our practical farmers.

2. *Subsoiling.*—The subsoil plough is an auxiliary to the drain. Though there are few subsoils through which the water will not at length make its way, yet there are some so stiff either naturally or from long consolidation, that the good effect of a well-arranged line of drains is lessened by the

slowness with which they allow the superfluous rains to pass through them. In such cases, the use of the subsoil plough is most advantageous in loosening the under layers of clay, and allowing the water to find a ready escape downwards and to either side until it reach the drains.

It is well known that if a piece of stiff clay be cut into the shape of a brick, and then allowed to dry, it will contract and harden—it will form an air-dried brick, almost impervious to any kind of gas—wet it again, it will swell and become still more impervious. Cut up *while wet*, it will only be divided into so many pieces, each of which will harden when dry, or the whole of which will again attach themselves and stick together if exposed to pressure. But tear it asunder *when dry*, and it will fall into many pieces, will more or less crumble, and will readily admit the air into its inner parts. So it is with a clay subsoil.

After the land is provided with drains, the subsoil being very retentive, the subsoil plough is used to open it up—to let out the water and to let in the air. If this is not done, the stiff under-clay will contract and bake as it dries, but it will neither sufficiently admit the air nor open a free passage for the roots. But let this operation be performed when the clay is still too wet, a good effect will follow, in the first instance; but after a while, the cut clay will again cohere, and the former will pronounce subsoiling to be a useless expense *on his land*. Defer the use of the subsoil plough till the clay is dry—it will then *tear* and *break* instead of *cutting*, and its openness will remain. Once give the air free access, and it, after a time, so modifies the drained clay, that it no longer has an equal tendency to cohere.

Mr. Smith of Deanston very judiciously recommends that the subsoil plough should never be used till at least a year after the land has been thoroughly drained. This in many cases will be a sufficient safeguard—will allow a sufficient time for the clay to dry; in other cases two years may not be too much. But this precaution has by some been neglected, and subsoiling being with them a failure, they have sought, in some supposed chemical or other quality *of their soil*, for the cause of a want of success which is to be found in their own neglect of a most necessary precaution. Let not the practical man be too *hasty* in desiring to attain those benefits which attend the adoption of improved modes of culture; let him give every method a fair trial; *and above all, let him make his trial in the way and with the pre-*

cautions recommended by the author of the method, before he pronounce its condemnation.

3. *Deep-ploughing*, like subsoiling, aids the effect of the drains, and so far, and where it goes nearly as deep, more completely effects the same object. But independent of this, it has other uses and merits, and where it has been successfully applied, has improved the land by the operation of other causes.

Subsoiling only lets out the water, and allows access to the air and a free passage to the roots. Deep-ploughing, in addition to these, brings new earth to the surface, forms thus a deeper soil, and more or less alters both its physical qualities and its chemical constitution.

If the plough be made to bring up two inches of clay or sand, it will stiffen or loosen the soil, as the case may be, or it may affect its colour or density. It is clear and simple enough, therefore, that by deep-ploughing the physical properties of the soil may be altered.

But there are certain substances contained in every soil, whether in pasture or under the plough, which gradually make their way down towards the subsoil. They sink till they reach at last that point beyond which the plough does not usually penetrate. Every farmer knows that lime thus sinks. In peat-soils top-dressed with clay, the clay thus sinks. In sandy soils also which have been clayed, the clay sinks; and in all these cases, I believe, the sinking takes place more rapidly when the land is laid down to grass. Where soils are marled, the marl sinks; and the rains, in like manner, gradually wash out that which gives their fertilizing virtue to the under chalk-soils (see page 88), and render necessary a new application from beneath, to renovate its productive powers.

If this be the case with earthy substances such as those now mentioned, which are insoluble in water, it will be readily believed that those saline ingredients of the soil which are readily soluble will be still sooner washed out of the upper and conveyed to the under soil. Thus the subsoil may gradually become rich in those substances of which the surface-soil has been robbed. Bring up a portion of this subsoil by deep-ploughing, and you restore to the land a portion of what it has lost—substances, perhaps, which may render it much more fruitful than before. Such is an outline of the theory of deep-ploughing, and it is entirely unexceptionable.

But suppose the land to have originally contained something noxious to vegetation, which in process of time has been washed down into the subsoil, then to bring this again to the surface would be materially to injure the land. This also is true, and a sound discretion must no doubt be employed, in judging when and where such evil effects are likely to follow.

Such cases, however, are more rare than many suppose. There are few subsoils which a full and fair exposure to a winter's frost will not in a great degree deprive of all their noxious qualities, and render fit to ameliorate the general surface of the poorer lands. If the reader doubt this fact, let him visit Yester, and give a calm consideration to the efforts produced by the use of deep-ploughing on the home-farm of the Marquis of Tweeddale.

In many cases the farmer fears, as he does in the county of Durham, to bring up a single inch of the yellow clay that lies beneath his soil. In the first inch lodges, among other substances, the iron worn from his plough, which in some soils, and after a lapse of years, amounts to a considerable quantity. Till it is exposed to the air, this iron is hurtful to vegetation, and one of the benefits of a winter's exposure of such subsoils to the air, is the effect produced upon the iron it contains.

It is the want of drainage, however, and of the free access of air, that most frequently renders subsoils for a time injurious to vegetation. Let the lands be well drained—let the subsoils be washed for a few years by the rain-water passing through them,—and there are few of those which are clayey in their nature that may not ultimately be brought to the surface, not only with safety, but with advantage to the soil.

4. *Ploughing.*—Other benefits, again, attend upon the ordinary ploughings, hoeings, and workings of the land. Its parts are more minutely divided—the air gets access to every particle—it is rendered lighter, more open, more permeable to the roots. The vegetable matter it contains decomposes more rapidly by a constant turning of the soil, so that wherever the fibres of the roots penetrate, they find organic food provided for them, and an abundant supply of the oxygen of the atmosphere to aid in preparing it. The production of ammonia and of nitric acid also (see pages 33 to 36), and the absorption of one or both from the air, take place to a greater extent, the finer the soil is pulverised, and the more it has been exposed to the action of the atmosphere. The general advantage, indeed, to be derived from the constant working of the soil, may be inferred

from the fact, that Tull reaped twelve successive crops of wheat from the same land by the repeated use of the plough and the horse-hoe. There are few soils so stubborn as not to shew themselves grateful in proportion to the amount of this kind of labour that may be bestowed upon them.

5. *Mixing.*—It has been shewn (page 114), that the physical properties of the soil have an important influence upon its average fertility. The admixture of pure sand with clay soils produces an alteration which is often beneficial, and which is wholly physical. The sand merely opens the pores of the clay, and makes it more permeable to the air.

The admixture of clay with sandy or peaty soils, however, produces both a physical and a chemical alteration. The clay not only consolidates and gives body to the sand or peat, but it also mixes with them certain earthy and saline substances useful or necessary to the plant, which neither the sand nor peat might originally contain in sufficient abundance. It thus alters its chemical constitution, and fits it for nourishing new races of plants.

Such is the case also with admixtures of marl, of shell-sand, and of lime. They slightly consolidate the sands and open the clays, and thus improve the mechanical texture of both kinds of soil, but their main operation is chemical; and the almost universal benefit they produce depends upon the new chemical element they introduce into the constitution of the soil.

It is a matter of almost universal remark, that in our climate soils are fertile—clayey or loamy soils, that is—only when they contain an appreciable quantity of lime. In whatever way it acts, therefore, the mixing of lime in any of the forms above mentioned, with a soil in which little or no lime exists, is one of the surest practical methods of bringing it nearer in composition to those soils from which the largest returns of agriculture produce are usually obtained. Some of the chemical effects of the lime upon the soil will be explained in a subsequent section. (See page 195.)

SECTION II.—OF THE CHEMICAL METHOD OF IMPROVING THE SOIL BY THE USE OF MANURES.

None of the above methods of improving the soil are mechanical only—they all involve some chemical alterations also, which are readily to be explained by a knowledge of elementary chemical principles. But the manuring of the land is more strictly a chemical operation, and may therefore with propriety be separated from those methods of improving its quality which involve at the same time important and expensive mechanical operations.

In commencing the tillage of a piece of land, the conscientious farmer may have three objects in view in regard to it.

1. He may wish to reclaim a waste, or to restore a neglected farm to an average condition of fertility.

2. Finding the land in this average state, his utmost ambition may be to keep it in its present condition; or,

3. By *high* farming he may wish to develope all its capabilities, and to increase its permanent productiveness in the greatest possible degree.

The man who aims at the last of these objects is not only the best tenant and the best citizen, but he is also his own best friend. The highest farming, skilfully and prudently conducted, is also the most remunerating.

But whichever of these three ends he aims at, he will be unable to attain it without a due knowledge of the various manures it may be in his power to apply to his land—what these manures are, or of what they consist—the general and special purposes they are each intended to serve—

which are the most effective for this or that crop —how they are to be obtained in the greatest abundance, and at the least cost—how their strength may be economized,—and in what state and at what seasons they may be most beneficially applied to the land. Such are a few of the questions which the skilful farmer should be ready to ask himself, and should be able to answer.

By a *manure* is to be understood whatever is capable of feeding or of supplying food to the plant. And as plants require earthy and saline as well as vegetable food, gypsum and nitrate of soda are as properly called manures as farm-yard dung, bone-dust, or night-soil.

Manures naturally divide themselves into such as are of *vegetable*, of *animal*, and of *mineral* origin.

I. OF VEGETABLE MANURES.

There are two purposes which vegetable manure is generally supposed to serve when added to the soil. It loosens the land, opens its pores, and makes it lighter; and it also serves to supply organic food to the roots of the growing plant. It serves, however, a third purpose: it yields to the roots those saline and earthy matters which it is their duty to find in the soil, and which exist in decaying plants in a state more peculiarly fitted to enter readily into the circulating system of new races.

Decayed vegetable matters, therefore, are in reality mixed manures, and their value in enriching the land must vary considerably with the *kind* of plants and with the *parts* of those plants of which they are chiefly made up. This depends upon the remarkable difference which exists in the *quantity* and *kind* of inorganic matter present in different vegetable substances, as indicated by the ash they leave (see pages 52 to 62). Thus if 1000 lbs. of the saw-dust of the willow be fermented, and added to the soil, they will enrich it by the addition of only 4½ lb. of saline and earthy matter, while 1000 lbs. of the dry leaves of the same tree fermented, and laid on, will add 82 lbs. of inorganic matter. Thus, independent of the effect of the vegetable matter in each, the one will produce a very much greater effect upon the soil than the other.*

There are three states in which vegetable matter is collected by the husbandman for the purpose

* It is owing to this large quantity of saline and othe inorganic matter that fermented leaves form too strong a dressing for flower borders, and that gardeners therefore generally mix them up into a compost.

of being applied to the land—the *green* state; the *dry* state; and that state of imperfect decay in which it forms *peat*.

1. *Green Manuring*.—When grass is mown in the field, and laid in heaps, it speedily heats, ferments, and rots. But, if turned over frequently and dried into hay, it may be kept for a great length of time without undergoing any material alteration. The same is true of all other vegetable substances—they all rot more readily in the green state. The reason of this is, that the sap or juice of the green plant begins very soon to ferment in the interior of the stem and leaves, and speedily communicates the same condition to the moist fibre of the plant itself. When once it has been dried, the vegetable matter of the sap loses this easy tendency to decay, and thus admits of long preservation.

The same rapid decay of green vegetable matter takes place when it is buried in the soil. Thus the cleanings and scourings of the ditches and hedge-sides form a compost of mixed earth and fresh vegetable matter, which soon becomes capable of enriching the ground. When a green crop is ploughed into a field, the whole of its surface is converted into such a compost—the vegetable matter in a short time decays into a light, black mould, and enriches in a remarkable degree and fertilizes the soil.

Hence the practice of green manuring has been in use from very early periods. The second or third crop of *lucerne* was ploughed in by the ancient Romans—as it still is by the modern Italians. In Tuscany, the *white lupin* is ploughed in, in preference—in Germany, *borage*. In French Flanders, two crops of *clover* are cut, and the third is ploughed in. In Sussex, *turnip* seed has been sown at the end of harvest, and after two months again ploughed in, with great benefit to the land. Turnip leaves and potato tops decay more readily, and more perfectly, and are more enriching when buried in the green state. It is a prudent economy, therefore, where circumstances admit of it, to bury the potato tops on the spot from which the potatoes are raised. Since the time of the Romans, it has been the custom to bury the cuttings of the vine stocks at the roots of the vines themselves; and many vineyards flourish for a succession of years without any other manuring.

Buckwheat, winter tares, clover, and rape, are all occasionally sown for the purpose of being ploughed in. This should be done *when the flower* *has just begun to open*, and if possible at a season when the warmth of the air and the dryness of the soil are such as to facilitate decomposition.

That the soil should become richer in vegetable matter by this burial of a crop than it was before the seed of that crop was sown, and should also be otherwise benefitted, will be understood by recollecting (see page 42) that perhaps three-fourths of the whole organic matter we bury has been derived from the air—that by this process of ploughing in, the vegetable matter is more equally diffused through the whole soil than it could ever be by any merely mechanical means;—and that by the natural decay of this vegetable matter, ammonia and nitric acid are, to a greater extent (pages 33 and 34), produced in the soil, and its agricultural capabilities in consequence materially increased.

These considerations, while they explain the effect and illustrate the value of green manuring, will also satisfy the intelligent agriculturist that there are methods of improving his land without the aid either of town or of foreign manures—and that he overlooks an important natural means of wealth who neglects the green sods and crops of weeds that flourish by his hedgerows and ditches. Left to themselves, they ripen their seeds and sow them annually in his fields—collected in compost heaps they would materially add to his yearly crops of corn.

Sea-weeds.—Among green manures, the use of fresh sea-ware deserves especial mention, from the remarkably fertilizing properties it is known to possess, as well as from the great extent to which it is employed on all our coasts. The produce of the isle of Thanet in Kent is said to have been doubled or tripled by the use of this manure; the farms on the Lothian coasts are said to be let for 20s. or 30s. more rent when they have a right of way to the sea, where the weed is thrown on shore; and in the Western Isles the sea-ware, the shell-marl, and the peat-ash, are the three great natural fertilizers to which the agriculture of the district is indebted for the comparative prosperity to which it has in some of the islands already attained.

Sea-weeds decompose with great ease when collected in heaps or spread upon the land. During their decay, they yield not only organic food to the plant but saline matters also, to which much of their efficacy both on the grass and the corn crops is no doubt to be ascribed.

2. *Manuring with dry Vegetable Matter.*—Almost every one knows that the saw-dust of most

common woods decays very slowly—so slowly, that it is rare to meet with a practical farmer who considers it worth the trouble of mixing with his composts. This property of slow decay is possessed in a certain degree by all *dry* vegetable matter. Heaps of dry straw alone, or even mixed with earth, will ferment with comparative difficulty and with great slowness. It is necessary, therefore, to mix it, as is usually done, with some substance that ferments more readily, and which will impart its own condition to the straw. Animal matters of any kind, such as the urine and droppings of cattle, are of this character; and it is by admixture with these that the straw which is trodden down in the farm-yard is made to undergo a more or less rapid fermentation.

The object of this fermentation is twofold—first, to reduce the particles of the straw to such a minute state of division, that they may admit of being diffused through the soil; and, second, that the dry vegetable matter may be so changed by exposure to the air, and other agencies, as to be fitted to yield both organic and inorganic food to the roots of the plants it is intended to nourish.

We have seen that this decomposition takes place very speedily, and of its own accord, when the vegetable matter is green, but that it can be *induced* or brought on in the case of dry straw by the agency of animal matter. The same means will cause the fermentation of any other vegetable substance which is in a minute state of division. Even saw-dust made into a compost heap with soil or sods, and watered regularly and copiously with the liquid manure of the farm-yards, may be thus converted into a fertilizing vegetable mould.

Differences of opinion have prevailed, and discussions have taken place, as to the relative efficacy of long and short—or of half fermented and of fully rotten dung. But if it be added *solely* for the purpose of yielding food to the plant, or of preparing food for it, the case is very simple. The more complete the state of fermentation—if not carried too far—the more immediate will be the agency of the manure; hence the propriety of the application of short dung to turnips and other plants it is desirable to bring rapidly forward; but if the manure be only half decayed, it will require time in the soil to complete the decomposition, so that its action will be more gradual and prolonged.

Though in the latter case the immediate action is not so perceptible, yet the ultimate benefit to the soil, and to the crops, may be even greater, supposing them to be such as require no special forcing at one period of the year. With a view to this slow amelioration, vegetable matter of any kind may be added with benefit, if in a sufficient state of division, to the soil. Even saw-dust applied largely to the land, has been found to improve it, though little at first, yet more during the second year after it was applied, still more during the third, and most of all in the fourth season after it was mixed with the soil. That any dry vegetable matter, therefore, does not produce an immediate effect, ought not to induce the practical farmer to despise the application to his land—either alone, or in the form of a compost—of every thing of the kind he can readily obtain. If his fields are not already very rich in vegetable matter, both he and they are likely to be ultimately benefitted by such additions to the soil.

Rape Dust.—It is from the straw of the corn-bearing plants, or from the stems and leaves of the grasses, that the largest portion of the strictly vegetable manures applied to the soil is generally obtained or prepared. But the seeds of all plants are much more enriching than the substance of their leaves and stems. These seeds, however, are in general too valuable for food to admit of their application as a manure. Still the refuse of some, as that of different kinds of rape-seed after the oil is expressed, and which is unpalatable to cattle, is applied with great benefit to the land. Drilled in with spring wheat, or scattered as a top-dressing in spring at the rate of 5 cwt. to an acre, it gives a largely increased and remunerating return. It is applied with equal success to the cultivation of potatoes, and generally it may be substituted for farm-yard manure at the rate of about 1 cwt. of rape-dust for each ton of manure.

Malt Dust consists of the dried sprouts of barley, which, when the sprouted seed is dried in the process of malting, break off and form a coarse powder. This is found to be almost equal to rape dust in fertilizing power.

Charcoal Powder possesses the remarkable property of absorbing noxious vapours from the air and soil, and unpleasant impurities from water. It also sucks into its pores much oxygen from the air. Owing to these and other properties, it is a valuable substance for mixing with liquid manure, night-soil, farm-yard manure, ammoniacal liquor, or other rich applications to the soil. It is even capable by itself of yielding slow supplies of nourishment to living plants, and is said, in many cases, without any admixture, to have been used with advantage in practical agriculture. In moist charcoal the seeds of the gardener are found to sprout with remarkable quickness and certainty.

Soot, whether from the burning of wood or of coal, is of vegetable origin, and consists chiefly of a finely-divided charcoal, possessing the properties above mentioned. It contains, however, ammonia and certain other substances in small quantity, to which its well known, and especially its *immediate*, effects upon vegetation are in part to be ascribed.

3. *The use of Peat.*—In many parts of the world, and in none more abundantly, perhaps, than in Gt. Britain, is vegetable matter collected in the form of peat. This ought to supply an inexhaustible store of organic matter for the amelioration of the adjacent soils. We know that by draining off the sour and unwholesome water, and afterwards applying lime and clay, the surface of peat bogs may be gradually converted into rich corn-bearing lands. It must, therefore, be possible to convert peat itself by a similar process into a compost fitted to improve the condition of other soils.

The late Lord Meadowbank, who made many important experiments on this subject, found, that after being partially dried by exposure to the air, peat might be readily fermented, and brought into the state of a rich fertilizing compost by the same means which are adopted in the ordinary fermenting of straw. He mixed with it a portion of animal matter, which soon communicated its own fermenting quality to the surrounding peat, and brought it readily in to a proper heat. He found that one ton of hot fermenting manure, mixed in alternate layers with two of half dry peat, and covered by the same, was sufficient to ferment the whole; and subsequently that the vapours which rise from naturally fermenting farm-yard manure or animal matters, would alone produce the same effect upon peat, placed so as readily to receive and absorb them.

As ammonia is one of the compounds specially given off by putrifying animal substances, it is not unlikely that a watering with *ammoniacal liquor* would materially prepare the peat for undergoing fermentation. At all events it seems possible to prepare any quantity of valuable peat compost by mixing the peat with a still less quantity of fermented manure than was employed by Lord Meadowbank, provided the liquid manure of the farm-yard be collected in a cistern, and be thrown at intervals by means of a pump over the prepared heaps.

One important use also to which I think peat may be applied is, after it is partly dried, to build it into covered heaps, and half burn or char it till it become readily reducible into a fine powder. In this state it would be of great value as a mixture to preserve the virtues of liquid manures of all kinds, of night-soil, and of ammoniacal liquor.

SECTION III.—RELATIVE VALUE OF DIFFERENT VEGETABLE MANURES.

There are two principles on which the relative value of different vegetable substances, as manures, may be stated to depend—*first*, on the relative quantity and kind of *inorganic matter* they contain; and *second*, on the relative proportions of *nitrogen* present in each.

1. Valued according to the *quantity* of inorganic matter they contain—the worth of the several kinds of straw and hay would be represented by the following numbers :—

Wheat straw, ...	70 to 360
Oat straw, ...	100 to 180
Hay, ...	100 to 200
Barley straw, ...	100 to 120
Pea straw, ...	100
Bean straw, ...	60 to 80
Rye straw, ...	50 to 70

Dry potato tops, ...	100
Dry turnip tops, ...	260
Rape, cake	120

that is, *a ton weight* of each of these substances, when made into manure—provided nothing is washed out by the rains—will return to the soil the above quantities of inorganic matter *in pounds*. Generally, perhaps, these numbers will give the reader an idea of the relative *permanent* effect of these different kinds of vegetable matter when laid upon the soil. But, by a reference to the facts stated in pp. 58 to 64, in regard to the *quality* of the inorganic matter contained in plants, he will satisfy himself, that the effect of these manures on particular crops is not to be judged of solely by the absolute quantity of earthy and saline matter they contain;—that which the turnip-top, for example, or the bean-stalk, returns to the soil, may not be exactly what will best promote the growth of wheat.

2. On the other hand, if the fertilizing value of vegetable substances is to be calculated by the relative quantities of nitrogen they severally contain, we should place them in the following order:—the number opposite to each substance representing that weight of it in pounds, which would produce

the same effect as 100 pounds of farm-yard manure, consisting of the mixed droppings and litter of cattle.

	Equivalent quantities in pounds.
Farm-yard manure, ...	100
Wheat straw, ...	80 to 170
Oat straw, ...	150
Barley straw, ...	180
Buckwheat, ...	85
Pea straw, ...	45
Wheat chaff, ...	50
Green grass, ...	80
Potato tops, ...	75
Fresh sea-weed, ...	80
Rape dust, ...	8
Fir saw-dust, ...	250
Oak saw-dust, ...	180
Coal soot, ...	30

This table again presents the same substances in a somewhat different order of value; shewing, for example, not only that such substances as rape-dust and soot should produce a much more remarkable effect upon vegetation, than the same weight even of farm-yard manure, but also that certain dry vegetables, such as chaff and pea-straw, will yield, when not unduly fermented, a more enriching manure than barley, oat, or wheat straw. It agrees, also, with the known effect of green manuring upon the land, since 80 pounds of meadow-grass ploughed in, will be equal in virtue to 100 of farm-yard manure.

Some writers ascribe the *entire* action of these measures to the nitrogen they contain. This, however, is taking a one-side view of their real natural operation. The nitrogen, during their decay, is liberated chiefly in the form of ammonia—an evanescent substance, producing an immediate effect in hastening or carrying further forward the growth of the plant, but not remaining permanently in the soil. The reader, therefore, will form an opinion consistent alike with theory and with practice, if he conclude—

1. That the *immediate* effect of a vegetable manure, in hastening the growth of plants, is dependent, in a great degree, upon the quantity of nitrogen it contains and gives off during its decay in the soil.

2. That the *permanent* effect and value of manures is to be estimated chiefly by the quantity and quality of the inorganic matter they contain—of the ash they leave when burned.

The effect of the nitrogen may be nearly expended in a single season—that of the earthy and saline matter may not be exhausted for several years.

Nor is the carbon of vegetable substances without its important uses to vegetation. From the statements contained in the earlier chapters of the present work, it may be inferred that, however much influence we may allow to the nitrogen and to the earthy matter of plants in aiding the growth of future races—the soundest view of these important natural operations is that which considers each element present in decaying plants to be capable of ministering food to such as are still alive, —though we may not be able as yet, either to estimate the precise importance of each element to any particular kind of crop, or exactly to adjust their relative quantities in our manures, so as to promote the growth of such a crop in the greatest possible degree.

CHAPTER IX.

Animal Manures—Their relative value and mode of Action —Difference between Animal and Vegetable Manures—Cause of this difference—Mineral Manures—Nitrates of Potash and Soda—Sulphate of Soda, Gypsum, Chalk, and Quicklime—Chemical action of these Manures—Artificial Manures—Burning and Irrigation of the Soil—Planting and laying down to grass.

The animal substances employed as manure consist chiefly of the flesh, blood, bones, horns, and hair of animals, of fish—which in some places are found in sufficient quantity to be laid upon the land—and of the solid and liquid excrements of animals and birds.

SECTION I.—OF UNDIGESTED ANIMAL MANURES.

Animal substances, in general, act more powerfully as manures than vegetable substances—it is only the seeds of plants which can at all compare with them in efficacy.

The *flesh* of animals is rarely used as a manure, except in the case of dead horses, or cattle which cannot be used for food. Fish is chiefly applied in the form of the refuse of the herring and pilchard fisheries, though occasionally such shoals of sprats, herrings, and even mackerel, have been caught on our shores, as to make it necessary to employ them as manure. These recent animal substances are found to be too *strong* when applied directly to the land; they are generally, therefore, made into a compost, with a large quantity of soil. Five barrels of fish, or fish refuse, made into twenty loads of compost, will be sufficient for an acre. The refuse of fish oils,—of the fat of animals that has been melted for the extraction of the tallow—of skins that have been boiled for the manufacture of glue —horns, hair, wool (woollen rags), and all similar substances, when made into composts, exercise, in proportion to their weight, a much greater influence upon vegetation than any of the more abundant forms of vegetable matter.

Even the bodies of insects are in many parts of the world important manures of the soil. In warm climates, a handful of soil sometimes seems almost half made up of the wings and skeletons of dead insects—the peasant in Hungary and Carinthia occasionally collects as many as thirty cart-loads of dead marsh flies in a single year;—and in the richer soils of France and England, where worms and other insects abound, the presence of their remains in the soil must also aid its natural productiveness.

Blood is rarely applied to the land directly—though, like the other parts of animals, it makes an excellent compost. As it comes from the sugar refineries, however, in which, with lime water and animal charcoal, it is employed for the refining of sugar, it has obtained a very extensive employment, especially in the south of France. This animal black, or *animalized charcoal*, as it is sometimes called, contains about twenty per cent. of blood, and has risen to such a price in France, that the sugar refiners actually sell it for more than the unmixed blood and animal charcoal originally cost them. This has given rise to the manufacture of artificial mixtures of charcoal, fecal matters, and blood, which are also sold under the name of animalized charcoal. The only disadvantage attending these artificial preparations is, that they are liable to be adulterated, or, for cheapness, prepared in a less efficient manner.

Horn, *hair*, and *wool*, depend for their efficacy precisely on the same principles as the blood and flesh of animals. They differ chiefly in this, that they are *dry*, while blood and flesh contain 80 to

90 per cent. of their weight of water. Hence, a ton of horn shavings, of hair, or of dry woollen rags, ought to enrich the soil as much as ten tons of blood. In consequence, however, of their dryness, the horn and wool decompose much more slowly than the blood. Hence, the effect of soft animal matters is more immediate and apparent, that of hard and dry substances less visible, but continuing for a much longer period of time.

Bones, again, while they resemble horn in being dry, differ from it in containing, besides the animal matter, a large quantity of earthy matter also, and hence they introduce a new agent to aid their effect upon the soil. Thus, the bones of the cow consist of 100 lbs. of

Phosphate of lime, ...	55½
Phosphate of magnesia, ...	3
Soda and common salt, ...	3½
Carbonate of lime, ...	3¾
Fluoride of calcium, ...	1
Gelatine (the substance of *horn*), . . .	33¼
	100

While 100 lbs. of bone-dust, therefore, add to the soil as much *organic* animal matter as 33 lbs. of horn, or as 300 or 400 lbs. of blood or flesh, they add, at the same time, much *inorganic* matter —lime, magnesia, soda, common salt, and phosphoric acid (in the phosphates),—all of which, as we have seen, must be present in a fertile soil, since the plants require a certain supply of them all at every period of their growth. These substances, like the inorganic matter of plants, may remain in the soil, and may exert a beneficial action upon vegetation after all the organic or gelatinous matter has decayed and disappeared.

From what is above stated, therefore, the reader will gather these general conclusions:

1. That animal substances which, like flesh and blood, contain much water, decay rapidly, and are fitted to operate *immediately* and powerfully upon vegetation, but are only temporary or evanescent in their action.

2. That when dry, as in horn, hair, and wool, they decompose, and consequently act more slowly, and continue to manifest an influence, it may be, for several seasons.

3. That bones, acting like horn, in so far as their animal matter is concerned, and, like it, for a number of seasons, more or less, according as they have been more or less finely crushed—may ameliorate the soil by their earthy matter for a still longer period—permanently improving the condition and adding to the natural capabilities of the land.

SECTION II.—OF DIGESTED ANIMAL MANURES.

Practical men have long been of opinion that the digestion of food, either animal or vegetable, —the passing of it through the bodies of animals, —enriches its fertilizing power, weight for weight, when added to the land. Hence, in causing animals to eat up as much of the vegetable productions of the farm as possible, it is supposed that not only is so much food saved, but that the value of the remainder in fertilizing the land is greatly increased. In a subsequent section we shall see how far theory serves to throw light upon these opinions. (See Section IV., p. 182 to 186.)

I. LIQUID EXCRETIONS.

The digested animal substances usually employed as manures are, the urine of the cow and the sheep, the solid excrements of the horse, the cow, the sheep, and the pig, the droppings of pigeons and other birds, and night-soil. The liquid manures act chiefly through the saline substances they hold in solution, while the solid manures contain also insoluble matters, which decay slowly in the soil, and there become useful only after a time. The former, therefore, will influence vegetation more powerfully at first; the action of the latter will be less evident, but will continue to operate for a much longer period.

Urine.—Human urine consists, in 1000 parts, of

Water, ...	932
Urea, and other organic matters containing nitrogen,	49
Phosphates of ammonia, lime, soda, and magnesia,	6
Sulphates of soda and ammonia, . .	7
Sal ammoniac and common salt, . .	6
	1000

A thousand pounds of urine therefore contain 68 lbs. of dry fertilizing matter of the richest quality, worth, *at the present rate of selling artificial manures in this country*, at least 20s. a cwt. As each person voids almost 1000 lb. of urine in a year, the national waste incurred in this form amounts, at the above valuation, to 12s. a head. And if five tons of farm-yard manure per acre, added year by year, will keep a farm in good heart, four cwt. of the solid matter of urine would probably have an equal effect; or the urine alone discharged into the rivers by a population of 10,000 inhabitants would supply manure to a farm of 1500 acres, yielding a return of 4500 quarters of corn or an equivalent produce of other crops.

The urine of the cow is said to contain less water than that of man, though of course much must depend upon the kind of food with which it is fed. Reckoning, then, the large quantity of liquid manure that is yielded by the cow (2000 or 3000 gallons a year), we may safely estimate the solid matter given off by a healthy animal in this form in twelve months at 1200 to 1500 pounds weight, worth, *if it were in the dry state*, from £10 to £12 sterling. In the *liquid* state, the urine of one cow collected and preserved as it is in Flanders, is valued in that country at about £2 a year. Any practical farmer may calculate for himself, therefore, how much real wealth, taking it even at the Flemish value, is lost in his own farm-yard—how much of the natural means of reproductive industry passes into his drains or evaporates into the air.

This liquid manure is invaluable, when collected in tanks, for watering the manure and compost heaps, and thus hastening their decomposition; but great part of it may also be sprinkled directly upon the fields of grass and upon the young corn, with the best effects. It must, however, be permitted to stand till fermentation commences, and afterwards diluted with a considerable quantity of water, before it will be in the best condition for laying on the land.

Urate.—In order to obtain the virtues of animal urine in a concentrated form, the custom has been adopted of mixing burnt gypsum with it, in the proportion of 10 lbs. to every 7 gallons, allowing the mixture, occasionally stirred, to stand some time, pouring off the liquid, and drying and crushing the gypsum. This is sold by manure manufacturers under the name of *urate*. It never can possess, however, the virtues of the urine, since it does not contain the soluble saline substances, which the gypsum does not carry down with it. Except the gypsum, indeed, 100 lbs. of urate contain no greater weight of saline and organic matter than 10 gallons of urine. If it be true, then, as the manufacturers state, that 3 or 4 cwt. of urate are sufficient manure for an acre, the practical farmer will, I hope, draw the conclusion,—not that it is well worth his while to venture his money in trying a portion of it upon a piece of his land,—but that a far more promising adventure will be to go to some expense in saving his own liquid manure, and, after mixing it with burned gypsum, to lay it abundantly upon all his fields.

II. SOLID EXCRETIONS.

Cow and Horse Dung.—So much of the saline, nutritive, and soluble organic matters from the cow pass off in the liquid form, that cow dung is correctly called cold, since it does not readily heat and run into fermentation. Mixed with other manures, however, or well diffused through the soil, it aids materially in promoting vegetation. The horse being fed generally on less liquid food, and discharging less urine, yields a hotter and richer dung, which, however, answers best also when mixed with other varieties. The dung of the swine is soft and *cold*, like that of the cow, containing, like it, at least 75 per cent. of water. As this animal lives on more varied food than any other reared for the use of man, the manure obtained from it is also very variable in quality. Applied alone, as a manure to roots, it is said to give them an unpleasant taste, and even to injure the flavour of tobacco. It answers best for hemp, and, it is said, also for hops; but, mixed with other manures, it may be applied to any crop.

Night-soil is probably the most valuable, and yet, in Europe at least, the most disliked and neglected of all the solid animal manures. It varies no doubt in richness with the food of the inhabitants of each district,—chiefly with the quantity of animal food they consume,—but when dry, no other solid manure, weight for weight, can probably be compared with it in general efficacy. It contains much soluble and saline matter, and as it is made up from the constituents of the food we eat, of course it contains most of those elementary substances which are necessary to the growth of the plants on which we principally live.

Attempts have been made to dry this manure also, so as to render it more portable,—to destroy its unpleasant smell, so as to reconcile practical men to a more general use of it,—and by certain chemical additions, to prevent the waste of ammonia and other volatile substances, which are apt to escape and be lost when this and other powerful animal manures begin to putrify through decay. In Paris, Berlin, and other large cities, the night-soil, dried first in the air with or without a mix ture of gypsum or lime, then upon drying plates, and finally in stoves, is sold under the name of *poudrette*, and is extensively exported in casks to various parts of the country. In London also it is dried with various mixtures, while in others of our large towns an *animalized charcoal* is prepared by mixing and drying night-soil with gypsum and ordinary wood charcoal in fine powder.

The half-burned peat above described (p. 80,) would answer well for such a purpose, while few simple and easily attainable substances would make a better compost with night-soil, and more thoroughly preserve its virtues, than half-dry peat or rich vegetable soil, mixed with more or less marl or gypsum. It is impossible to estimate the proportion of waste which this valuable manure undergoes by being allowed to ferment, without mixture, in the open air.

Taffo.—In China it is kneaded into cakes with clay, which are dried in the air, and, under the name of *taffo*, form an important article of export from all the large cities of the empire.

Pigeons' Dung.—The dung of all birds is found to possess eminent fertilizing virtues. Some varieties are stronger than others, or more immediate in their action, and all are improved for the use of the farmer by being some time kept, either alone or in compost. In Flanders the manure of one hundred pigeons is considered worth 20s. a year for agricultural purposes.

Guano is the name given by the natives of Peru to the dung of sea-fowl, which in former periods used to be deposited in vast quantities on the rocky shores and isles of the Peruvian coast. The numerous shipping of modern times has disturbed and driven away many of the sea-fowl, so that comparatively little of their recent droppings is now preserved or collected. Ancient heaps of it, however, still exist in many places, more or less covered up with drifted sand, and also more or less decomposed. These are now largely excavated for exportation, not only to different parts of the coast of Peru, as seems to have been the case from the most remote periods, but also to Europe, and especially to England. It is at present sold at 20s. a cwt. in this country, and is capable of entirely replacing farm-yard dung,—that is to say, turnips may be manured successfully with guano alone;—but it has not yet been satisfactorily determined that the English farmer can afford to use it in this way to any extent, at the price now asked for it.

The dung of birds possesses the united virtues of both the liquid and solid excretions of other animals. It contains every part of the food of the bird, with the exception of what is absolutely necessary for the support and for the right discharge of the functions of its own body. It is thus fitted, therefore, to return to the plant a greater number of those substances on which plants live, than either the solid or the fluid excrements of other animals; in other words, to be more nourishing to vegetable growth.

SECTION III.—OF THE RELATIVE GROWTH OF THE DIFFERENT ANIMAL MANURES.

The fertilizing power of animal manures, in general, is dependent, like that of the soil itself, upon the happy admixture they contain of a great number, if not of all, those substances which are required by plants in the universal vegetation of the globe. Nothing they contain, therefore, is without its share of influence upon their general effects, yet the amount of nitrogen present in each affords the readiest and most simple criterion by which their agricultural value, compared with that of vegetable matters and with that of each other, can be pretty nearly estimated.

In reference to their relative quantities of nitrogen, therefore, they have been arranged in the following order, the number opposite to each representing the weight in pounds which is equivalent to or would produce the same sensible effect upon the soil as 100 lbs. of farm-yard manure.

Farm-yard manure,	100
Solid excrements of the cow	125
" " " horse,	73
Liquid ditto of the cow,	91
" " " horse,	16
Mixed ditto of the cow,	98
" " " horse,	54
" " " sheep	36
" " " pig,	64
Dry flesh,	3
Pigeons' dung,	5
Flemish liquid manure,	200

Liquid blood, ...	15
Dry blood, ...	4
Feathers, ...	3
Cow hair, ...	3
Horn shavings, ...	3
Dry woollen rags, ...	2½

It is probable that the numbers in this table do not err very widely from the true relative value of these different manures, in so far as the *organic* matter they severally contain is concerned. The reader will bear in mind, however,

1. That the most powerful substances in this table, woollen rags, for example,—2½ lbs. of which are equal in virtue to 100 lbs. of farm-yard manure,—may yet shew less immediate sensible effect upon the crop than an equal weight of sheep's dung, or even of urine. Such dry substances are long in dissolving and decomposing, and continue to evolve fertilizing matter, after the softer and more fluid manures have spent their force. Thus, while farm-yard manure or rape dust will immediately hasten the growth of turnips, woollen rags will come into operation at a later period, and prolong their growth into the autumn.

2. That besides their general relative value, as represented in the above table, each of these sub-

stances has a further special value not here exhibited, dependent upon the kind and quantity of saline and other inorganic matter which they severally contain. Thus three of dry flesh are equal to five of pigeons' dung, in so far as the *organic* part is concerned; but the latter contains also a considerable quantity of bone earth and of saline matter scarcely present at all in the former. Hence pigeons' dung will benefit vegetation in circumstances where dry flesh would in some degree fail. So the liquid excretions contain much important saline matter not present in the solid excretions,—not present either in such substances as horn, wool, and hair,—and, therefore, each must be capable of exercising an influence upon vegetation peculiar to itself.

Hence the practical farmer sees the reason why no one *simple* manure can long answer on the same land; and why in all ages and countries the habit of employing *mixed* manures and artificial composts has been universally diffused.

SECTION IV.—NATURAL DISTINCTION OR DIFFERENCE BETWEEN ANIMAL AND VEGETABLE MANURES, AND THE CAUSE OF THIS DIFFERENCE.

In what do animal manures differ from vegetable manures,—what is the cause of this difference,—how does the digestion of vegetable matter improve its value as a manure?

1. The characteristic distinction between animal and vegetable manures is this,—that the former contain a much larger proportion of nitrogen than the latter. This will be seen at once, by comparing together the tables given in the two preceding sections, in which the numbers represent the relative agricultural values of certain animal and vegetable substances compared with farm-yard manure. The lowest numbers represent the highest value, and the largest amount of nitrogen, and these low numbers are always opposite to the purest animal substances.

2. In consequence of containing so much nitrogen, animal substances are further distinguished by the rapidity with which, when moist, they putrify or run to decay. During this decay the nitrogen they contain gradually assumes the form of ammonia, which is perceptible by the smell, and which, when proper precautions are not taken, is apt in great part to escape into the air. Hence the loss by fermenting manure too completely,—or without proper precautions to prevent the escape of volatile substances. And as animal manure, when thus over-fermented, or permitted to lose its ammonia into the air, is found much less active

upon vegetation than before; it is reasonably concluded, that to this ammonia, chiefly, their peculiar virtue, when rightly prepared, is in a great measure to be ascribed.

Vegetable substances do not decay so rapidly,—do not emit the odour of ammonia when fermenting,—nor, when prepared in the most careful way, does vegetable manure exhibit the same remarkable action upon vegetable life as is displayed by almost every substance of animal origin.

3. Whence do animal substances derive all this nitrogen? Animals live only upon vegetable productions containing little nitrogen; can they then procure all they require from this source alone? Again, does the act of digestion produce any chemical alteration upon the food of animals, that their excretions should be a better manure,—should be richer in nitrogen than the substances on which they feed? Does theory throw any light upon the opinion generally entertained among practical men upon this point?

These two apparently distinct questions will be explained by a brief reference to one common natural principle.

Animals have two necessary vital functions to perform,—to breathe and to digest. Both are of equal importance to the health and general welfare of the animal. The digester (the stomach) receives the food, melts it down, extracts from it what is best suited to its purposes, and conveys it into the blood. The breathers (the lungs) sift the blood thus mixed up with the newly digested food, combine oxygen with it, and extract carbon, —which carbon, in the form of carbonic acid, they discharge by the mouth and nostrils into the air.

Such is a general description of these two great processes,—their effect upon the food that remains in the body and has to be rejected from it, is not difficult to perceive.

Suppose an animal to be full grown. Take a full grown man. All that he eats as food is intended merely to renovate or replenish his system, to restore that which is daily removed from every part of his body by natural causes. *In the full grown state, every thing that enters the body must come out of the body* in one form or another. The first part of the food that escapes is that portion of its carbon that passes off from the lungs during respiration. This quantity varies in different individuals—chiefly according to the quantity of exercise they take. From 5 to 9 ounces a day is the average quantity, though in periods of violent bodily exertion 13 to 15 ounces of carbon are breathed out in the form of carbonic acid.

Suppose a man to eat a pound and a half of bread and a pound of beef in 24 hours, and that he gives off by respiration 8 ounces of carbon (3500 grains) during the same time. Then he has

	Carbon.	Nitrogen.
Taken, in his food, about	4500 grains, and	500 grs. while
He has given off in respiration, . .	3500 and	little or no nitrogen,
	——	——
Leaving to be converted into food, or to be rejected, . .	1000 grs. and	500 grs.

Our two conclusions, therefore, are clear. The vegetable food, by respiration, is freed from a large portion of its carbon, which is discharged into the air,—nearly the whole of the nitrogen remaining behind. In the food consumed the carbon was to the nitrogen as 9 to 1; in that which remains, after respiration has done its work, the carbon is to the nitrogen in the proportion of only 2 to 1.

It is out of this residue, rich in nitrogen, that the several parts of animal bodies are built up. Hence the reason why they can be formed from food poor in nitrogen, and yet be themselves rich in the same element.

It is this same residue also which, after it has performed its functions within the body, is discharged again in the form of solid and liquid excretions. Hence the greater richness in nitrogen,—the greater fertilizing power of the dung of animals than of the food on which they live.

Two other remarks I shall add for the benefit of the practical man.

1. The manure of the cow, taking it mixed, is not so rich in nitrogen as that of man,—because the cow in the stall, large though it be, and great the bulk of food it consumes, does not give off much more carbon by respiration than an active full grown man. Hence the proportion of carbon in the excretions of this animal is greater than in those of man. The dry manure is richer than the dry food, weight for weight, but not in the same proportion as if the cow respired a quantity of carbon more nearly corresponding to its bulk, when compared with the weight of carbon thrown off from the lungs of man.

2. Since the parts of animals—their blood, muscles, tendons, and the gelatinous portion of the bones—contain much nitrogen, young beasts which are growing, must appropriate to their own use, and work up into flesh and bone, a portion of the nitrogen contained in the *non-respired* part of their

food. But the more they thus appropriate, the less will pass off into the fold-yard; and hence it is natural to suppose that the manure, either liquid or solid, which is prepared where many growing cattle are fed, will not be so rich as that which is yielded by full-grown animals. I am not aware how far this deterioration has been observed in practice, but it may with some degree of certainty be expected to take place,—unless by giving a richer food to the young cattle, the difference to the farm-yard be made up.*

SECTION V.—OF MINERAL WATERS.

The general nature and mode of operation of such mineral substances as are capable of acting as manures, will be in some measure understood from what has already been so fully stated in regard to the necessity of inorganic food to living plants, and to the kinds of such food which they specially require. A slight no-

* Though I have dwelt as long upon these interesting and, I believe, novel considerations, as the limits of this little work will permit, yet I must refer the reader for fuller details, and to perhaps a clearer exposition of the principles above advanced than I have here been able to give, to my "LECTURES *on Agricultural Chemistry and Geology*."

tice, therefore, of the more important of these manures now in use will here be sufficient.

1. *Nitrates of Potash and Soda.*—Saltpetre and nitrate of soda have been deservedly commended for their beneficial action, especially upon *young* vegetation. They are distinguished by imparting to the leaves a beautiful dark green colour, and are applied with advantage to grass and young corn, at the rate of 1 cwt. to 1½ cwt. per acre. The nitric acid they contain yields nitrogen to the plant, while potash and soda are also put within reach of its roots, and no doubt serve many beneficial purposes.

Sulphate of Soda, or Glauber's salt, has lately been recommended in this country for clovers, grasses, and green crops. Mixed with nitrate of soda it produces remarkable crops of potatoes.*

Sulphate of Magnesia, or Epsom salts, might also be beneficially applied in agriculture, probably to clovers and corn crops. As it can be had in pure crystals at 10s. a cwt., and in an impure state at a much less price, from the alum works, it might readily be submitted to trial.

Sulphate of Lime, or Gypsum, is in Germany applied to grass lands with great success, over

* See the author's "*Suggestions for Experiments in Practical Agriculture*," Nos. 1 & 2

large tracts of country. In the United States it is used for every kind of crop. It is especially adapted to clovers and legumes.

These three substances all afford sulphur to the growing plant, while the lime, soda, and magnesia are themselves in part directly appropriated by it, and in part employed in preparing other kinds of food, and in conveying them into the ascending sap.

Though there can be no question that these and similar substances are really useful to vegetation, yet the intelligent reader will not be surprised to find, or to hear, that this or that mineral substance has not succeeded in benefitting the land in this or that district. If he has already bricks enough at hand, you must carry the builder mortar, or he will be unable to go on with his work: so, if the soil contain gypsum or sulphate of magnesia in sufficient natural abundance, it is at once a needless and a foolish waste to attempt to improve the land by adding more; it is still more foolish to conclude that these same saline compounds are unlikely to reward the patient experimenter in other localities.

Common Salt has undoubtedly, in very many districts, a fertilizing influence upon the soil. The theoretical agriculturist knows that a small quantity of it is absolutely necessary to the healthy growth of all our cultivated crops, and he will therefore, early try by a preliminary experiment upon one of his fields, whether or not they require the addition of this species of vegetable food. It is in inland and sheltered situations, and on high lands often washed by the rains, that the effect of common salt is likely to be most appreciable. The spray of the sea, borne to great distances by the winds, is in many districts, where prevailing sea winds are known, sufficient to supply an ample annual dressing of common salt to the land.

Kelp.—Among mineral substances kelp ought not properly to be included, since it is the ash left by the burning of sea-weed. It, however, partakes of the nature of mineral substances, and may, therefore, be properly considered in this place. It contains potash, soda, silica, sulphur, chlorine, and several other of the inorganic constituents of plants required by them for food. It is nearly the same also—with the exception of the organic matter which is burned away—with the sea-weed which produces such remarkably beneficial effects upon the soil. In the Western Isles a method is practised of half burning or charring sea-weed, by which it is prevented from melting together, and is readily obtained in the form of a fine black powder. The use of this variety ought to combine the beneficial action of the ordinary saline constituents of kelp, with the remarkable properties observed in animal and vegetable charcoals.

Wood-ash, among other compounds, contains a portion of common *pearl-ash* in an impure form, with sulphate also, and *silicate* of potash. These are all valuable in feeding and in preparing the food of plants, and hence the extensive use of wood-ash as a manure in every country where it can readily be procured.

Dutch ashes are the ashes of peat burned for the purpose of being applied to the land. They vary in constitution with the kind of peat from which they have been prepared. They often contain traces of potash and soda, and generally a quantity of gypsum and carbonate of lime, a trace of phosphate of lime, and much siliceous matter. In almost every country where peat abounds, the value of peat ashes as a manure has been more or less generally recognised.

SECTION VI.—USE OF LIME, SHELL-SAND, AND MARL.

The use of lime is of the greatest importance in practical agriculture. It has been employed, in

Europe at least, in one or other of its forms of shells, shell-sand, marl, chalk, limestone, and quicklime, from the most remote periods.

Native limestone, and all the unburned varieties of chalk, shells, &c. consist of *carbonate of lime* (p. 51), more or less pure. When burned in the kiln, the carbonic acid is driven off, and lime, burned lime, or quicklime remains.

Quicklime, when exposed to the air, gradually falls into the state of an exceedingly fine white powder. It will do so more rapidly if water be thrown upon it, when it also heats much, swells, and becomes about one-third heavier than before. After being exposed to the air for some time in this white powdery state, it is found to have again absorbed from the air a portion of carbonic acid, though a very long period generally elapses before it is all re-converted into carbonate. In compost heaps, where much carbonic acid is formed during the fermentation, the conversion of any quicklime that may be mixed with them into carbonate of lime, is much more rapid and complete than in the open air.

Lime, therefore, is laid on the land in two states.

1*st*, In the *mild* state—that of carbonate—in marls, in chalk, in shell-sand, &c.

2*d*, In the *caustic*, or quick state, as it comes hot from the kiln, or after it is simply slaked.

Limes are laid on also in a more or less pure form. Marl contains only from 5 to 20 per cent. of carbonate of lime, generally in the state of a very fine powder. Shell-sand consists of a mixture of minute fragments of shells with from 20 to 50 per cent. of siliceous sand. The limestones which are burned are also more or less impure, though, when the impurity is very great, they do not burn well, and are therefore usually rejected.

Some limestones contain much magnesia, by which their agricultural qualities are materially affected. These are known by the name of *magnesian* limestones. There are few limestones in which a small quantity of magnesia may not be detected, and this minute proportion is likely to be beneficial rather than otherwise; but when it is present to the amount of 10 per cent. or upwards, it appears to have for some time a poisonous influence upon vegetation, if added in the same large doses in which other lime may be safely spread upon the land.

The quantity of lime laid on at a single dressing, and the frequency with which it may be repeated, must depend upon the kind of land, upon the depth of the soil, and upon the species of culture to which it is subjected. If land be wet, or badly drained, a larger application is necessary to produce the same effect, and it must be more frequently repeated. When the soil is thin, again, a smaller addition will thoroughly impregnate the whole, than where the plough usually descends to the depth of 8 or 10 inches. On old pasture lands, where the tender grasses live in two or three inches of soil only, a feebler dressing, more frequently repeated, appears to be the more reasonable practice, though in reclaiming and laying down lands to grass, a heavy first liming is often indispensable.

In arable culture larger doses are admissible, both because the soil through which the roots penetrate must necessarily be deeper, and because the tendency to sink beyond the reach of the roots is generally counteracted by the frequent turning up of the earth by the plough. Where vegetable matter abounds, much lime may be usefully added, and on stiff clay lands after draining, its good effect is most remarkable. On light land, chiefly because there is neither moisture nor vegetable matter present in equal quantity, very large applications of lime are not so usual, and some prefer adding it to such lands in the shape of composts only.

The largest doses, however, which are applied in practice, alter in a very immaterial degree the chemical constitution of the soil. We have seen that the best soils generally contain a natural proportion of lime, not fixed in quantity, yet scarcely ever wholly wanting. But an ordinary liming, when well mixed up with a deep soil, will rarely amount to *one per cent.* of its entire weight. It requires about 300 bushels of burned lime per acre to add one per cent. of lime to a soil of twelve inches in depth; if only mixed to a depth of six inches, this quantity would add about two per cent. to the soil.

The most remarkable visible alterations produced by liming are—upon *pastures*, the greater fineness, closeness, and nutritive character of the grasses—on *arable lands*, the improvement in the texture and mellowness of stiff clays, the more productive crops and the earlier period at which they ripen.

But these effects gradually diminish year by year, till the land returns again nearly to its original condition. On analyzing the soil, the lime originally added is found to be in great measure, or altogether, gone. In this condition the land must either be limed again, or must be left to produce sickly and un-remunerating crops.

This removal arises from two causes. The rain water that descends upon the land holds in solution carbonic acid which it has absorbed from the air. But water charged with carbonic acid is capable of dissolving carbonate of lime, and thus year after year the rains slowly remove as they sink to the drains, or run over the surface, a portion of the lime which the soil contains. Acid substances are also formed naturally in the land, by which another portion of the lime is rendered easily soluble in water, and, therefore, readily removable by every shower that falls.

The *chemical* effects of lime upon the soil are chiefly the following:—

1. When laid upon the land in the *caustic* state, the first action of the lime is to combine immediately with every portion of acid matter it may contain, and thus to sweeten the soil. Some of the compounds it thus forms being soluble in water, either enter into the roots and feed the plant,—supplying it at once with lime and with organic matter,—or are washed out by the springs and rains, while other compounds, which are insoluble, remain more permanently in the soil.

2. Another portion decomposes certain saline compounds of iron, manganese, and alumina, which naturally form themselves in the soil, and thus renders them unhurtful to vegetation. A

similar action is exerted upon certain compounds of potash and soda, and of ammonia,—if any such are present,—by which these substances are set and placed within the reach of the plant.

3. Its presence in the caustic state further disposes the organic matter of the soil to undergo more rapid decomposition—it being observed, that where lime is present in readiness to combine with the substances produced during the decay of organic matter, that decay, if other circumstances be favourable, will proceed with much greater rapidity. The reader will not fail to recollect, that during this decay many compounds are formed which are of importance in promoting vegetation.

4. Further, quicklime has the advantage of being soluble in cold water, and thus the complete diffusion of it through the soil is aided by the power of water to carry it in solution in every direction.

5. When it has absorbed carbonic acid, and become reconverted into carbonate, the original caustic lime has no *chemical* virtue over chalk, rich shell-sand or marl, or crushed limestone. It has, however, the important *mechanical* advantage of being in the form of a far finer powder, than any to which we could reduce the limestone by art—in consequence of which it can be more uniformly

diffused through the soil, and placed within the reach of every root, and of almost every particle, of vegetable matter that is undergoing decay. I shall mention only three of the important purposes which, in this state of *carbonate*, lime serves upon the land.

1. It directly affords food to the plant, which, as we have seen, languishes where lime is not attainable. It serves also to convey other food to the roots in a state in which it can be made available to vegetable growth.

2. It neutralizes (removes the *sourness*) of all acid substances as they are formed in the soil, and thus keeps the land in a condition to nourish the tenderest plants. This is one of the important agencies of shell-sand when laid on undrained grass lands—and this effect it produces in common with wood-ashes, and many similar substances.

3. During the decay of organic matter in the soil, it aids and promotes the production of nitric acid,—so influential, as I believe, in the general vegetation of the globe (see page 35). With this acid it combines and forms *nitrate of lime*—a substance very soluble in water—entering readily, therefore, into the roots of plants, and producing upon their growth effects precisely similar to those

of the now well known *nitrate of soda*. The success of frequent ploughings, harrowings, hoeings, and other modes of stirring the land, is partly owing to the facilities which these operations afford to the production of this and other natural nitrates.

SECTION VII.—OF THE IRRIGATION OF THE LAND.

The irrigation of the land is, in general, only a more refined method of manuring it. The nature of the process itself, however, is different in different countries, as are also the kind and degree of effect it produces, and the theory by which these effects are to be explained.

In dry and arid climates, where rain rarely falls, the soil may contain all the elements of fertility, and require only water to call them into operation. In such cases, as in the irrigations practised so extensively in eastern countries, and without which, whole provinces in Africa and Southern America would lie waste, it is unnecessary to suppose any other virtue in irrigation than the mere supply of water it affords to the parched and cracking soil.

But in climates such as our own, there are two other beneficial purposes in reference to the soil, which irrigation may, and one at least of which it always does, serve.

2. The occasional flow of *pure* water over the surface, as in our irrigated meadows, and its descent into the drains, where the drainage is perfect, washes out acid and other noxious substances naturally generated in the soil, and thus purifies and sweetens it. The beneficial effect of such washing will be readily understood in the case of peat lands laid down to water meadow, since, as every one knows, peat soils abound in matters unfavourable to general vegetation, and which are usually in part drawn off by drainage, and in part destroyed by lime and by exposure to the air, before boggy lands can be brought into profitable cultivation.

2. But it seldom happens that *pure* water is employed for the purposes of irrigation. The water of rivers, more generally, is diverted from its course, more or less loaded with mud and other finer particles of matter, which are either gradually filtered from it as it passes over and through the soil, or in the case of floods subside naturally when the waters come to rest. Or in less frequent cases, the drainings of towns, and the waters from common sewers, or from the little streams enriched by them, are turned with benefit upon the favoured fields. These are evidently cases

of gradual and uniform manuring. And even where the water employed is clear and apparently undisturbed by mud, it always contains saline substances grateful to the plant in its search for food, and which it always contrives to extract more or less copiously as the water passes over its leaves or along its roots. Every fresh access of water affords the grass in reality another liquid manuring.

In the refreshment continually afforded to the plant by a plentiful supply of water, in the removal of noxious substances from the soil, or in the frequent additions of enriching food to the land—the efficiency of irrigation, therefore, seems entirely to consist.

SECTION VIII.—OF PARING AND BURNING, AND OF BURNED CLAY.

A mode of improvement often resorted to is the paring and burning of poor land. The efficacy of burned clay, also, even in superseding manure on good lands, has been highly extolled by some practical men.

1. The effect of paring and burning is easily understood. The matted sods consist of a mixture of much vegetable with a comparatively small

quantity of earthy matter. When these are burned the ash of the plants only is left, intimately mixed with the calcined earth. To strew this mixture over the soil is much the same as to dress it with peat or wood ashes, the beneficial effect of which upon vegetation is almost universally recognised. And the beneficial influence of the ash itself is chiefly due to the ready supply of inorganic food it yields to the seed, and to the effect which the potash and soda it contains exercise either in preparing organic food in the soil, or in assisting its digestion and assimilation in the interior of the plant.

Another part of this process is, that the roots of the weeds and poorer grasses are materially injured by the paring, and that the subsequent dressing of ashes is unfavourable to their further growth.

2. Much greater uncertainty hangs over the alleged virtues of burned clay. That benefits are supposed to have been derived from its use there can be no doubt, though in many cases the better tillage of the land generally prescribed along with the use of burned clay, may have had some share in producing the good results actually experienced during its use.

By the burning, in kilns or otherwise, any organic matter the clay may contain will be consumed, and the texture of the clay itself will be mechanically altered. It will crumble down like a burned brick into a hard friable powder, and will never again cohere into a paste as before the burning. It will, therefore, render clay soils more open, and may thus, when mixed in large quantity, produce a permanent amelioration in the mechanical texture of many stiff wheat soils. It cannot itself undergo any chemical change that is likely so to alter its constitution as to make it a more useful chemical constituent of the soil than before. Any saline matter we may suppose to be set free could be far more cheaply added in the form of a top-dressing to the soil.

Bricks, however, are generally more porous than the clay from which they are formed; burned clay is so also. And all porous substances suck in and *condense* much air and many vapours in large quantities into their pores. In consequence of this property, porous substances, like charcoal and burned clay, are supposed, when mixed with the soil, to be continually yielding air to decaying vegetable matter on the one hand, and as continually re-absorbing it from the atmosphere on the other, and by this means to be of singular service in supplying the wants of plants in the earlier seasons of their growth. The vapours of nitric acid and of ammonia, which float in the air, they are also supposed to imbibe, and by the beneficial action of the substances believed to be thus conveyed by burned clay into the soil, the fertilizing virtues ascribed to it are attempted to be explained.

It must be confessed, however, that on this point considerable obscurity still rests. It is in some measure doubtful what the true action of charcoal and of burned clay is, both in *kind* and in *quantity*. It is the part of science, therefore, to decline offering more than a mere conjecture till the facts to be explained are more fully and satisfactorily demonstrated.

SECTION IX.—PLANTING AND LAYING DOWN TO GRASS.

1. *Planting.*—It has been observed that lands which are unfit for arable culture, and which yield only a trifling rent as natural pasture, are yet in many cases capable of growing profitable plantations, and of being greatly increased in permanent value by the prolonged growth of wood. Not only, however, do all trees not thrive alike on the same soil, but all do not improve the soil on which they grow in an equal degree.

Under the Scotch fir, for example, the pasture is not worth 6d. more per acre than before it was planted—under the beech and spruce, it is worth even less than before, though the spruce affords excellent shelter ;—under ash, it gradually acquires an increased value of 2s. or 3s. per acre. In oak copses, it becomes worth 5s. or 6s., but only during the last eight years (of the twenty-four), before it is cut down. But under the larch, after the first thirty years, when the thinnings are all cut, land not worth originally more than 1s. per acre, becomes worth 8s. to 10s. per acre for permanent pasture.*

The cause of this improvement is to be found in the nature of the soil, which gradually accumulates beneath the trees by the shedding of their leaves. The shelter from the sun and rain which the foliage affords, prevents the vegetable matter which falls from being so speedily decomposed, or from being so much washed away, and thus permits it to collect in larger quantities in a given time, than where no such cover exists. The more complete the shelter, therefore, the more rapid will the accumulation of soil be in so far as it depends upon this cause.

But the quantity of leaves which annually falls

* The result of trials made on the *mica slate* and *gneiss soils* (see page 100) of the Duke of Atholl.

has also much influence upon the extent to which the soil is capable of being improved by any given species of tree, as well as the degree of rapidity with which those leaves, under ordinary circumstances, undergo decay. The broad membranous leaf of the beech and oak decay more quickly than the needle-shaped leaves of the pine tribes, and this circumstance may assist in rendering the larch more valuable as a permanent improver.

We should expect likewise that the quantity and quality of the inorganic matter contained in the leaves,—brought up year by year from the roots, and strewed afterwards uniformly over the surface where the leaves are shed,—would materially affect the value of the soil they form. The leaves of the oak contain about 5 per cent. of saline and earthy matter, and those of the Scotch fir less than 2 per cent.; so that, supposing the actual weight of leaves which falls from each kind of tree to be equal, we should expect a greater depth of soil to be formed in the same time by the oak than by the Scotch fir. I am not aware of any experiments on the quantity of ash left by the leaves of the larch.

The improvement of the land, therefore, by the planting of trees, depends in part upon the quantity of *organic* food which the trees can extract from the air, and afterwards drop in the form of leaves upon the soil, and in part upon the kind and quantity of *inorganic* matter which the roots can bring up from beneath, and in like manner strew upon the surface. The quantity and quality of the latter will, in a great measure, determine the kind of grasses which will spring up, and the consequent value of the pasture in the feeding of stock. In the larch districts of the Duke of Athol, the most abundant grasses that spring up are said to be the holcus mollis and the holcus lanatus, (the *creeping* and the *meadow* soft-grasses.)

2. *Laying down to grass.*—On this point two facts seem to be pretty generally acknowledged:

First, that land laid down to artificial grasses for one, two, three, or more years, is in some degree rested or recruited, and is fitted for the better production of after-corn crops. Letting it lie a year or two longer in grass, therefore, is one of the received modes of bringing back to a sound condition a soil that has been exhausted by injudicious cropping.

Second, that land thus laid down with artificial grasses deteriorates more or less after two or three years, and only by slow degrees acquires a thick sward of rich and nourishing herbage. Hence the opinion, that grass-land improves in quality the longer it is permitted to lie,—the unwillingness to plough up old pasture,—and the comparatively high rents which, in some parts of the country, old grass lands are known to yield.

Granting that grass lands do thus *generally* increase in value, *three* important facts must be borne in mind before we attempt to assign the cause of this improvement, or the circumstances under which it is likely to take place for the longest time and to the greatest extent.

1. The value of the grass in any given spot may increase for an indefinite period—but it will never improve beyond a certain extent—it will necessarily be limited, as all other crops are, by the quality of the land. Hence the mere laying down to grass will not make *all* land *good*, however long it may lie. The extensive commons, heaths, and wastes, which have been in grass from the most remote times, are evidence of this. They have in most cases yielded so poor a herbage as to have been considered unworthy of being enclosed as a permanent pasture.

2. Some grass lands will retain the good condition they thus slowly acquire for a very long period, and *without manuring*, in the same way, and upon the same principle, that some rich corn lands have yielded successive crops for 100 years

without manure. The rich grass lands of England, and especially of Ireland, many of which have been in pasture from time immemorial, without, it is said, receiving any return for all they have yielded, are illustrations of this fact.

3. But that others, if grazed, cropped with sheep or meadowed, will gradually deteriorate, unless some proper supply of manure be given to them,—which required supply must vary with the nature of the soil, and with the kind of treatment to which it has been subjected.

In regard to the acknowledged benefit of laying down to grass, then, two points require consideration,—what form does it assume?—and how is it effected?

1. The improvement takes place by the gradual accumulation of a dark-brown soil on the surface, rich in vegetable matter: and which soil thickens or deepens in proportion to the time which elapses from its being first laid down to grass.

If the soil be very light and sandy, the thickening is sooner arrested; if it be moderately heavy land, the improvement continues for a longer period; and some of the heaviest clays in England are known to bear the richest permanent pastures. On analyzing the soils of the richest of these pastures, whatever be the degree of tenacity of the clays or loams (the subsoils) on which they rest, or their deficiency in vegetable matter,—they are found to be generally characterized by containing from 8 to 12 per cent. of organic, chiefly vegetable matter, from 5 to 10 only of alumina, and from 1 to 6 per cent. of lime.

Thus the soil formed on the surface of all rich old pasture lands is possessed of a remarkable degree of uniformity,—both in physical character and in chemical composition. This uniformity they gradually *acquire*, even upon the stiff clays of the Lias and of the Oxford clay, which originally, no doubt, have been,—as many clay lands still are, —left to natural pasture from the difficulty and expense of submitting them to arable culture.

2. But how do they acquire this new character, and why is it the work of so much time? When the young grass throws up its leaves into the air, from which it derives so much of its nourishment, it throws down its roots into the soil in quest of food of another kind. The leaves may be mown or cropped by animals, and carried off the field, but the roots remain in the soil, and, as they die, gradually fill its upper part with vegetable matter. It is not known what average proportion the roots of the natural grasses bear to the leaves; no doubt it varies much, both with the kind of

grass and with the kind of soil. When wheat is cut down, the quantity of straw left in the field, in the form of stubble and roots, is sometimes greater than the quantity carried off in the sheaf. Upon a grass field two or three tons of hay may be reaped from an acre; and if we suppose only a tenth part of this quantity to die every year in the form of roots or parts of roots, or of excretions from roots, we can easily understand how the vegetable matter in the soil thus gradually accumulating, should at length become very considerable in quantity. In arable land this accumulation is prevented by the constant turning up of the soil, by which the vegetable fibres being exposed to the free access of air and moisture, are made to undergo a more rapid decomposition.

But the roots and leaves of the grasses contain inorganic earthy and saline matter also. Dry hay leaves from an eighth to a tenth part of its weight of ash when burned. Along with the dead vegetable matter of the soil, this inorganic matter accumulates also on the surface, in the form of an exceedingly fine earthy powder; hence *one* cause of the universal fineness of the surface mould of old grass fields. And the earthy portion of this inorganic matter consists chiefly of silica and lime, with scarcely a trace of alumina, so that, even on the stiffest clays, a surface soil may be ultimately formed, in which the quantity of alumina will be comparatively small.

But there are still other agencies at work by which the surface of stiff soils is made to undergo a change. As the roots penetrate into the clay, they more or less open up a way into it for the rains. Now the rains in nearly all lands, when they have a passage downwards, have a tendency to carry down the clay along with them. They do so, it has been observed, on sandy and peaty soils, and more quickly when these soils are laid down to grass. Hence the mechanical action of the rains,—slowly in many localities, yet surely,—has a tendency to lighten the soil, by removing a portion of its clay. They constitute one of those natural agencies by which, as elsewhere explained, important differences are ultimately established, almost everywhere, between the surface crop-bearing soil and the subsoil on which it rests.

But further, the heats of summer and the frosts of winter aid this slow alteration. In the extremes of heat and of cold, the soil contracts more than the roots of the grasses do; and similar though less striking differences take place during the changes of temperature experienced in our climate in a single day. When the rain falls on the parched field, or when a thaw comes on, the earth expands, while the roots of the grasses remain nearly fixed; hence the soil rises up among the leaves, mixes with the vegetable matter, and thus assists in the slow accumulation of a rich vegetable mould.

The reader has witnessed in winter how, on a field or a by-way side, the earth rises above the stones, and appears inclined to cover them; he may even have seen in a deserted and undisturbed highway, the stones gradually sinking and disappearing altogether, when the repetition of this alternate contraction and expansion of the soil for a succession of winters has increased in a great degree the effects which follow from a single accession of frosty weather.

So it is in the fields. And if a person skilled in the soils of a given district can make a guess at the time when a given field was laid down to grass, by the depth at which the stones are found beneath the surface, it is because this loosening and expansion of the soil, while the stones remain fixed, tends to throw the latter down by an almost imperceptible quantity every year that passes.

Such movements as these act in opening up the surface-soil, in mixing it with the decaying vegetable matter, and in allowing the slow action of the rains gradually to give its earthy portion a lighter character. But with these, among other causes, conspire also the action of living animals. Few persons have followed the plough without occasionally observing the vast quantities of earth-worms with which some fields seem to be filled. On a close shaven lawn many have noticed the frequent little heaps of earth which these worms during the night have thrown out upon the grass. These and other minute animals are continually at work, especially beneath an undisturbed and grassy sward—and they nightly bring up from a considerable depth, and discharge on the surface, their burden of fine fertilizing loamy earth. Each of these burdens is an actual gain to the rich surface soil, and who can doubt that in the lapse of years, the unseen and unappreciated labours of these insect tribes must both materially improve its quality and increase its depth ?

There are natural causes, then, which we *know* to be at work, that are sufficient to account for nearly all the facts that have been observed, in regard to the effect of laying lands down to grass. Stiff clays will gradually become lighter on the surface, and if the subsoil be rich in all the kinds of inorganic food which the grasses require, will go on improving for an indefinite period without the aid of manure. Let them, however, be deficient, or let them gradually become exhausted of any one kind of this food, and the grass lands will either gradually deteriorate after they have reached a certain degree of excellence—or they must be supplied with that ingredient—that manure of which they stand in need. It is doubtful if any pasture-lands are so naturally rich as to bear to be cropped for centuries without the addition of manure, and at the same time without deterioration.*

On soils that are light, again, which naturally contain little clay, the grasses will thrive more rapidly, a thick sward will be sooner formed, but the tendency of the rains to wash out the clay may prevent them from ever attaining that luxuriance which is observed upon the old pastures of the clay-lands.

On undrained heaths and commons, and generally on any soil which is deficient in some fertilizing element, neither abundant herbage, nor good crops of any other kind, can be expected to flourish. Laying such lands down, or permitting them to remain in grass, may prepare them for by-and-by yielding one or two average crops of corn, but cannot be expected *alone* to convert them into valuable pasture.

* See pages 240 and 241.

Finally, plough up the old pastures, on the surface of which this light and most favourable soil has been long accumulating—and the heavy soil from beneath will be again mixed up with it—the vegetable matter will disappear rapidly by exposure to the air,—and if again laid down to grass, the slow changes of many years must again be begun through the agency of the same natural causes, before it become capable of again bearing the same rich herbage it was known to nourish while it lay undisturbed.

Many have supposed that by sowing down with the *natural* grasses, a thick sward may at once be obtained—and on light loamy lands, rich in vegetable matter, this method may, to a certain extent, succeed—but on heavy lands, in which vegetable matter is defective, disappointment will often follow the sowing of the most carefully selected seeds. By the agency of the causes above adverted to—*the soil gradually changes*, so that it is unfit, when first laid down, to bear those grasses which, ten or twenty years afterwards, will naturally and luxuriantly grow upon it.

CHAPTER X.

The Products of Vegetation—Importance of *Chemical* quality as well as quantity of Produce—Influence of different Manures on the quantity and quality of the Crop—Influence of the time of Cutting—Absolute quantity of Food yielded by different Crops—Principles on which the Feeding of Animals depends—Theoretical and experimental value of different kinds of Food for Feeding Stock—Concluding Observations.

The first object of the practical farmer is, to reap from his land the largest possible return of the most valuable crops, without permanently exhausting the soil. With this view he adopts one or other of the methods of treatment above adverted to, by which either the physical condition or the chemical constitution of the soil is altered for the better. It may be useful to shew how very much both the quantity and the quality of a crop is dependent upon the mode in which it is cultivated and reaped, and how much control, therefore, the skilful agriculturist really possesses over the ordinary productions of nature.

SECTION I.—OF THE INFLUENCE OF MANURE ON THE QUANTITY OF THE WHEAT AND OTHER CORN CROPS.

Every one knows that some soils naturally produce much larger returns of wheat, oats, and barley than others do, and that the same soil will produce more or less according to the mode in which the land has been prepared by manure, or otherwise, for the reception of the seed. The following table shews the effect produced upon the quantity of the crop by *equal quantities* of different manures applied to the *same soil*, sown with an equal quantity of the same seed.

Manure applied.	Return in bushels from each bushel of seed.			
	Wheat.	Barley.	Oats.	Rye.
Blood,	14	16	12½	14
Night soil,	—	13	14½	13½
Sheep's dung,	12	16	14	13
Horse dung,	10	13	14	11
Pigeon's dung,	—	10	12	9
Cow dung,	7	11	16	9
Vegetable matter,	3	7	13	6
Without manure,	—	4	5	4

It is probable that on different soils the returns obtained by the use of these several manures may not be always in the same order, yet, generally speaking, it will always be found that blood, night-soil, and sheep, horse, and pigeon's dung, are among the most enriching manures that can be employed.

We have already seen a theoretical reason for believing that night-soil should be among the most enriching manures, and the result of actual trial here shews that it is one of the most practically valuable which the farmer can employ.

Two other facts will strike the practical man on looking at the above table.

1. That exclusive of blood, sheep's dung gave the greatest increase in the barley crop. The favourite Norfolk system of eating off turnips with sheep previous to barley, besides other benefits which are known to attend the practice, may owe part of its acknowledged utility to this powerful action of sheep's dung upon the barley crop.

2. The action of cow-dung upon oats is equally striking, and the large return obtained by the use of vegetable manure alone—thirteen fold—may perhaps explain why in poorly farmed districts oats should be a favourite and comparatively profitable crop, and why they may be cultivated

with a certain degree of success on lands to which no rich manure is ever added.

SECTION II.—INFLUENCE OF THE KIND OF MANURE ON THE CHEMICAL QUALITY OF THE GRAIN.

But the quality of the grain also, as well as its quantity, is materially affected by the kind of manure by which its growth is assisted. The apparent quality of wheat and oats is very various; but in samples apparently equal in quality, important chemical differences may exist, by which it is believed that the nourishing properties of the grain are materially affected.

It has been stated in a previous chapter (p. 43), that when flour is made into dough, and this dough is washed upon a linen cloth with water as long as the latter passes through milky,—the flour is separated into *starch*, which subsides from the water, and *gluten*, which remains behind. The quantity of gluten thus left varies more or less with almost every sample of flour, and the nutritive properties of each sample are supposed to depend very much upon the quantity of gluten it contains. So far it seems to be pretty well ascertained, that those varieties of grain which contain the largest amount of gluten yield also the greatest return of flour, and the heaviest weight of bread.

The weight of gluten contained in 100 lbs. of dry wheat has been found to vary from 8 to 34 lbs., and this proportion is affected in a very remarkable manner by the kind of manure which has been applied to the land. Thus the proportions of starch and gluten in 100 lbs. of the grain of the same wheat, grown on the same land, differently manured, was as follows:—

Manure.	Starch.	Gluten.
Blood, ...	41 lbs.	34 lbs.
Sheep's dung, . . .	42 —	33 —
Horse dung, . . .	62 —	14 —
Cow dung, . . .	62 —	12 —
Vegetable manure, . .	66 —	10 —

Potato-flour, which consists entirely of starch, makes a fine light bread, easily raised. Wheaten-flour, which contains little gluten, approaches in this respect to potato-flour. When the quantity of gluten is large, greater care is required to make a good light bread; but the bread from such flour is generally found to be more nutritive in its quality. A dough peculiarly rich in gluten is required for the manufacture of macaroni and vermicelli; such is said to be the flour naturally produced in southern Italy. By the above table it appears, that the use of richer animal, or poorer vegetable manures, would enable the farmer to raise, at his pleasure, either a rich macaroni wheat, or one poor in gluten suited for the makers of fancy bread.

An equally striking effect is not produced upon other kinds of grain by varying the manure. Thus the proportions of starch and gluten in the dry grain of barley and oats, differently manured, were found to be as follows :—

	BARLEY.		OATS.	
	Starch.	Gluten.	Starch.	Gluten.
Blood,	66½	6½	60	5½
Night-soil,	66	6½	60	5
Sheep dung,	66½	6½	61	4½
Horse dung,	66	6½	61½	4½
Cow dung,	69	3½	62	3½
Vegetable manure,	69	3	66½	2¼
Unmanured,	69½	3	66½	2¼

Though a variation in the proportion of gluten can be observed in both of these kinds of grain, according as one or other of the above kinds of manure was employed, yet neither the average quantity of gluten present in them, nor the variations to which the quantity is liable, are at all equal in amount to what are observed in the case of wheat.

The malting of barley is known to be affected by a variety of circumstances. It should be so uniform in ripeness as to sprout uniformly, so that no part of it should be beginning to shoot when the rest has already germinated sufficiently for the malter's purpose. On this perfect sprouting of the *whole* depends in some degree the swelling of the malt, which is of considerable consequence to the manufacturer.

But the *melting* quality of the grain, which is of more consequence to the brewer and distiller, is modified chiefly by the proportion of gluten which the barley contains. That which contains the least gluten, and therefore the most starch, will melt the most easily and the most completely, and will yield the strongest beer or spirit from the same quantity of grain. Hence the preference given by the brewer to the malt of particular districts, even where the sample appears otherwise inferior. Thus the brewers on the sea-board of the county of Durham will not purchase the barley of their own neighbourhood, while Norfolk grain can be had at a moderate increase of price. But that which refuses to melt well in the hands of the brewer, will cause pigs and other stock to thrive well in the hands of the feeder, and this is the chief outlet for the barley which the brewer and distiller reject.

So far as a practical deduction can be drawn from the effects of different manures on the proportion of gluten in barley, it would appear that the larger the quantity of cow-dung contained in the manure applied to barley land—in other words, *the greater the numbers of stock folded about the farm-yard, the more likely is the barley to be such as will bring a high price from the brewer.*

The folding of *sheep* produces a larger return (p. 206), from the barley crop—while the folding of *cattle* gives grain of a better malting quality.

SECTION III.—INFLUENCE OF THE TIME OF CUTTING, ON THE QUANTITY AND QUALITY OF THE PRODUCE.

The period at which hay is cut, or corn reaped, materially affects the quantity (by weight) and the quality of the produce. It is commonly known that when radishes are left too long in the ground they become hard and woody—that the soft turnippy stem of the young cabbage undergoes a similar change as the plant grows old,—and that the artichoke becomes tough and uneatable if left too long uncut. The same natural change goes on in the grasses which are cut for hay.

In the blades and stems of the young grasses there is much sugar, which, as they grow up, is gradually changed, first into starch, and then into woody fibre (pages 44 and 45.) The more completely the latter change is effected—that is, the riper the plant becomes—the less sugar and starch, both readily soluble substances, they contain. And though it has been ascertained that woody fibre is not wholly indigestible, but that the cow, for example, can appropriate a portion of it for food as it passes through her stomach; yet the reader will readily imagine, that those parts of the food which dissolve most easily, are also likely—other things being equal—to be most nourishing to the animal.

It is ascertained, also, that the weight of hay or straw reaped, is actually less when allowed to become fully ripe; and therefore, by cutting soon after the plant has attained its greatest height, a larger quantity, as well as a better quality of hay, will be obtained, while the land also will be less exhausted.

The same remarks apply to crops of corn,—both to the straw and to the grain they yield. The *rawer* the crop is cut, the heavier and more nourishing the straw. Within three weeks of being fully ripe, the straw begins to diminish in weight, and the longer it remains uncut after that time, the lighter it becomes and the less nourishing.

On the other hand, the ear which is sweet and milky a month before it is ripe, gradually consolidates, the sugar changing into starch, and the milk thickening into the gluten and the *albumen** of the flour. As soon as this change is nearly completed, or about a fortnight before ripening, the grain contains the largest proportion of starch and gluten; if reaped at this time, the bushel will be heavier, and will yield the largest quantity of fine flour and the least bran.

At this period the grain has a thin skin, and hence the small quantity of bran. But if the crop be still left uncut, the next natural step in the ripening process is, to cover the grain with a better protection, a thicker skin. A portion of the starch of the grain is changed into woody fibre,—precisely as in the ripening of hay, of the soft shoots of the dog-rose, and of the roots of the common radish. By this change, therefore, the quantity of starch is lessened and the weight of husk increased; hence the diminished yield of flour, and the increased produce of bran.

Theory and experience, therefore, indicate about

* *Albumen* is the name given by chemists to the *white of the egg*. A small quantity of this substance is present in every kind of grain. It is closely related to gluten.

a fortnight before full ripening as the most proper time for cutting corn. The skin is then thinner, the grain fuller, the bushel heavier, the yield of flour greater, the quantity of bran less; while, at the same time, the straw is heavier, and contains more soluble matter than when it is left uncut until it is considered to be fully ripe.*

SECTION IV.—ON THE ABSOLUTE QUANTITY OF FOOD YIELDED BY DIFFERENT CROPS.

The quantity of food capable of yielding nourishment to man, which can be grown from an acre of land of average quality, depends very much upon the kind of crop we raise.

In seeds, when fully ripe, little sugar or gum is generally present, and it is chiefly by the amount of starch and gluten they contain, that their nutritive power is to be estimated. In bulbs, such as the turnip and potato, sugar and gum are almost always present in considerable quantity in the state

* On this subject the reader will consult with advantage an excellent practical paper in the *Quarterly Journal of Agriculture* for June 1841, by Mr. Hannam of North Deighton, Yorkshire, to whom I have to express my obligations for information regarding the results of some further experiments made by him during the last autumn (1841).

in which these roots are consumed, and this is especially the case with the turnip. These substances, therefore, must be included among the nutritive ingredients of such kinds of food.

If we suppose an acre of land to yield the following quantities of the usually cultivated crops, namely—

Of wheat, . .	25 bushels,	or 1500 lbs.
Of barley, . .	38 "	or 2000 "
Of oats, . . .	50 "	or 2250 "
Of peas, . .	15 "	or 1000 "
Of beans, . .	25 "	or 1600 "
Of Indian corn, .	60 "	or 3120 "
Of potatoes, . .	10 tons,	or 22400 "
Of turnips, . .	25 "	or 56000 "

The weight of dry starch, gluten, sugar, and gum, reaped in each crop, will be represented very nearly by the following numbers :—

	Starch.	Gluten and Albumen.	Sugar and Gum.	Woody Fibre.
Wheat, . .	825 lbs.	315 lbs.	60	—
Barley, . .	1200 "	120 "	160	—
Oats, . .	1215 "	100 "	250	—
Peas, . .	420 "	260 "	20	—
Beans, . .	670 "	370 "	—	—
Indian corn, .	2100 "	280 "	90	—
Potatoes, . .	2688 "	224 "	—	1253
Turnips, . .	3090 "	1400 "	5000	—

If it be granted that the crops above stated are fair average returns from the same quality of land—that the acre, for example, which produces 25 bushels of wheat, will also produce 10 tons of potatoes, and so on—then it appears that the land which, by cropping with wheat, would yield a given weight of *starch*, would, when cropped with barley or oats, yield one-half more, with Indian corn or potatoes about three times as much, and with turnips five times the same quantity. In other words, the piece of ground which, when sown with wheat, will maintain one man, would support one and a half if sown with barley or oats, three with Indian corn or potatoes, and five with *turnips—in so far as the nutritive power of these crops depends upon the starch and sugar they contain.*

Again, if we compare the relative quantities of gluten, we see that wheat, beans, and Indian corn yield, from the same breadth of land, nearly an equal quantity of this kind of nourishment—potatoes one-third less, and barley and oats only one-third of the quantity—while turnips yield four times as much as either wheat, beans, or Indian co n.

On whichever of these two substances, therefore, the starch or the gluten, we consider the nutritive property of the above kind of food to depend, it appears that the turnip is by far the most nutritive crop we can raise. It is by no means the most nutritive weight for weight, but the largeness of the crop (25 tons) affords us from the same field a much greater weight of food than can be reaped in the form of any of the other crops here mentioned.

In this the practical farmer will see the peculiar adaptation of the turnip husbandry to the rearing and fattening of stock. Could the turnip be made an agreeable article of general human consumption, the produce of the land might be made to sustain a much larger population than under any other of the above kinds of cropping.

The relative nourishing power or value as food of different vegetable substances, is supposed by some to depend entirely upon the relative proportions of gluten they contain. According to this view, the pea and the bean are much more nourishing, weight for weight, even than wheat, and this latter grain, than any of the other substances mentioned in the above table. Thus, 56 lbs. of beans would afford as much sustenance to an animal as 67 of pease, 100 of wheat-flour, or 177 *of rice.*

In order to understand the value of this opinion, it will be proper to consider the several purposes which the food is destined to serve in the animal economy—what the animal must derive from its food to maintain its existing condition, or to admit of a healthy increase of bulk.

SECTION V.—OF THE FEEDING OF ANIMALS, AND THE PURPOSES SERVED BY THE FOOD THEY CONSUME.

The food of plants we have seen to consist essentially of two kinds, the *organic* and the *inorganic*, both of which we have insisted upon as equally necessary to the living vegetable—equally indispensable to its healthy growth. A brief glance at the purposes served by plants in the feeding of animals, will not only confirm this view, but will also throw some additional light upon the *kind* of inorganic food which the plants must be able to procure, in order that they may be fitted to fulfil their assigned purpose in the economy of nature.

Man, and all domestic animals, may be supported, may even be fattened, upon vegetable food alone: vegetables, therefore, must contain all the substances which are necessary to build up the several parts of animal bodies, and to supply the waste attendant upon the performance of the necessary functions of animal life. Let us consider what these substances are, and in what quantities they must be supplied to the human body.

1. *The food must supply carbon for respiration.* A man of sedentary habits, or whose occupation requires little bodily exertion, may respire about 5 ounces of carbon in twenty-four hours —one who takes moderate exercise, about 8 ounces —and one who has to undergo violent bodily exertion, from 12 to 15 ounces.

If we take the mean quantity of 8 ounces, then to supply this alone, a man must eat 18 ounces of starch or sugar every day. If he take it in the form of wheaten bread, he will require $1\frac{3}{4}$ lbs. of bread, if in the form of potatoes, about $7\frac{1}{2}$ lbs. of raw potatoes, to supply the waste caused by his respiratory organs alone.

When the habits are sedentary, 5 lbs. of potatoes may be sufficient, when violent and continued exercise is taken, 12 to 15 lbs. may be too little. At the same time, it must be observed, that where the supply is less, the quantity of carbonic acid given off will either be less also, or the deficiency will be supplied at the expense of the body itself. In either case the strength will be impaired, and fresh food will be required to recruit the exhausted frame.

2. *The food must repair the daily waste of the muscular parts of the body.*

When the body is full grown, a portion from every part of it is daily abstracted by natural processes, and rejected either in the perspiration or in the solid and fluid excrements. This portion must be supplied by the food, or the strength will diminish—the frame will gradually waste away.

The muscles of animals, of which lean beef and mutton are examples, are generally coloured by blood, but when well washed with water, they become quite white, and, with the exception of a little fat, are found to consist of a white fibrous substance, to which the name of *fibrin* has been given by chemists. The clot of the blood consists of the same substance; while skin, hair, horn, and the organic part of the bones, are composed of varieties of *gelatine*. This latter substance is familiarly known in the form of *glue*, and though it differs in its sensible properties, it is remarkably analogous to *fibrin* in its elementary constitution, as both of these substances are to the white of the egg (*albumen*), to the curd of milk (*casein*), and to the *gluten* of flour. They all contain nitrogen, and all consist of the four elementary bodies (organic elements), very nearly in the following proportions:—

Carbon, ...	55
Hydrogen, ...	7
Nitrogen, ...	18
Oxygen, ...	20
	100

They all contain, likewise, a small proportion of sulphur and of phosphorous.

The quantity of one or other of these removed from the body in 24 hours, either in the perspiration or in the excretions, amounts to *about five ounces,* containing 350 grains of nitrogen, and this waste at least must be made up by the gluten or fibrin of the food.

In the $1\frac{3}{4}$ lb. of wheaten bread we have supposed to be eaten to supply carbon for respiration, there will be contained also about 3 ounces of gluten. Let the other 2 ounces be made up in beef, of which half a pound contains 2 ounces of dry fibrin, and we have

	For respiration.	For waste of muscle, &c.
$1\frac{3}{4}$ lbs. of bread yielding	18 oz. starch and	3 oz. of gluten.
8 oz. of beef yielding	. .	2 oz. of fibrin.
Total consumed by respiration, and the ordinary waste,	18 oz. starch and	5 oz. gluten or fibrin.

If, again, the $7\frac{1}{2}$ lbs. of potatoes be eaten, then in these are contained about $2\frac{1}{2}$ ounces of gluten or albumen, so that there remain $2\frac{1}{2}$ ounces to be supplied by beef, eggs, milk, or cheese.

The reader, therefore, will understand why a diet which will keep up the human strength is easiest compounded of a mixture of vegetable and animal food. It is not merely that such a mixture is more agreeable to the palate, or even that it is absolutely necessary,—for, as already observed, the strength may be fully maintained by vegetable food alone;—it is, that without animal food in one form or another, so large a bulk of vegetable food must be consumed in order to supply the requisite quantity of nitrogen in the form of gluten. Of ordinary wheaten bread alone, about 3 lbs. daily must be eaten to supply the nitrogen,* and there would then be a considerable waste of carbon in the form of starch, by which the stomach would be overloaded, and which, not being worked up by respiration, would pass off in the excretions. The wants of the body would be equally supplied, and with more ease, by $1\frac{3}{4}$ lbs. of bread and 4 ounces of cheese.

Of rice, again, no less than 4 lbs. daily would

* The flour being supposed to contain 15 per cent. of dry gluten, on which supposition all the above calculations are made.

be required to impart to the system the required proportion of gluten; and it is a familiar observation of those who have been in India and other countries, where rice is the usual food of the people, that the degree to which the natives distend, and apparently overload their stomachs with this grain, is quite extraordinary.

The stomachs and other digestive apparatus of our domestic animals are of larger dimensions, and they are able, therefore, to contain with ease as much vegetable food, of almost any wholesome variety, as will supply them with the quantity of nitrogen they may require. Yet every feeder of stock knows that the addition of a small portion of oil-cake, a substance rich in nitrogen, will not only fatten an animal more speedily, but will also save a large *bulk* of other kinds of food.

3. But the blood and other fluids of the body contain much *saline* matter of various kinds, sulphates, muriates, phosphates, and other saline compounds of potash, soda, lime, and magnesia. All these have their special functions to perform in the animal economy, and of each of them an undetermined quantity daily escapes from the body in the perspiration, in the urine, or in the solid excretions. This quantity, therefore, must be daily restored by the food.

No precise experiments have yet been made with the view of determining how much saline matter is daily excreted from the body of a healthy man, or in what proportions the different inorganic substances are present in it; but it is satisfactorily ascertained, that without a certain *sufficient* supply, the animal will languish and decay, even though carbon and nitrogen in the form of starch and gluten be abundantly given to it. It is a wise and beautiful provision of nature, therefore, that plants are so organized as to refuse to grow in a soil from which they cannot readily obtain a supply of soluble inorganic food, since that saline matter which ministers first to their own wants is afterwards surrendered by them to the animals they are destined to feed.

Thus the dead earth and the living animal are but parts of the same system,—links in the same endless chain of natural existences,—the plant is the connecting bond by which they are tied together on the one hand,—the decaying animal matter which returns to the soil, connects them on the other.

4. The solid bones of the animal are supplied from the same original source,—the vegetable food on which they live. The bones of the cow contain 55 per cent. of phosphate of lime, of the sheep

70, of the horse 67, of the calf 54, and of the pig 52 lbs., in every hundred of dry bone. All this must come from the vegetable food. Of the bone-earth also, a portion,—perhaps a variable portion,—is every day rejected from the animal; the food, therefore, must contain a daily supply, or that which passes off will be taken from the substance of the bones, and the animal will become feeble.

It is kindly provided by nature, that a certain proportion of this ingredient of bones is always associated with the gluten of plants in its various forms,—with the fibrin of animal muscle and with the curd of milk. Hence, man, in using any of these latter along with his vegetable food, obtains from them, with comparative ease, the quantity of the earth of bones which is necessary to keep his system in repair; while those animals which live upon vegetables alone, extract all they require along with the gluten of the plants on which they feed.

The provision is very beautiful by which the young animal,—the muscle and bones of which are rapidly growing,—is supplied with a larger portion of nitrogenous food and of bone-earth, than are necessary to maintain the healthy condition of the full grown animal. The milk of the mother is the natural food from which its supplies are drawn. The sugar of the milk supplies the comparatively small quantity of carbon necessary for the respiration of the young animal; as it gets older, the calf or young lamb crops green food for itself to supply an additional portion. The curd of the milk (*casein*) yields the materials of the growing muscles, and of the animal part of the bones,—while dissolved along with the curd in the liquid milk is the phosphate of lime, of which the earthy part of the bones is to be built up. A glance at the constitution of milk will shew us how copious the supply of all these substances is, —how beautifully the constitution of the mother's milk is adapted to the wants of her infant offspring. Cow's milk consists in 1000 parts by weight of—

Butter,	27 to	35
Cheesy matter (casein),	45 to	90
Milk sugar,	36 to	50
Chloride of potassium, and a little chloride of sodium,	1½	} to 10
Phosphates, chiefly of *lime*,	2¼	
Other salts,	6	
Water,	882¼ to	815
	1000	1000

The quality of the milk, and, consequently, the proportions of the several constituents above mentioned, vary with the breed of the cow,—with the food on which it is supported,—with the time that has elapsed since the period of calving,—with its age, its state of health, and with the warmth of the weather;* but in all cases this fluid contains the same substances, though in different quantities.

Milk of the quality above analyzed contains, in every ten gallons, 4½ lbs. of casein, equal to the formation of 18 lbs. of ordinary muscle, and 3½ ounces of phosphate of lime (bone-earth), equal to the production of 7 ounces of dry bone. But from the casein have to be formed the skin, the hair, the horn, the hoof, &c. as well as the muscle, and in all these is contained also a minute portion of the bone-earth. A portion of all the ingredients of the milk likewise passes off in the ordinary excretions, and yet every one knows how rapidly young animals thrive, when allowed to consume the whole of the milk which nature has provided as their most suitable nourishment.

And whence does the mother derive all this gluten and bone-earth, by which she can not only repair the natural waste of her own full-grown body, but from which she can spare enough also

* In warm weather the milk contains more butter, in cold weather more cheese and sugar.

to yield so large a supply of nourishing milk? She must extract them from the vegetables on which she lives, and they again from the soil.

The quantity of solid matter thus yielded by the cow in her milk is really very large, if we look at the produce of an entire year. If the average yield of milk be 3000 quarts, or 750 gallons in a year—every 10 gallons of which contain bone-earth enough to form about 7 ounces of dry bone—then the milking of the cow alone exhausts her of the earthy ingredients of 33 lbs. of dry bone. And this she draws necessarily from the soil!

If this milk be consumed on the spot, then all returns again to the soil in the annual manuring of the land. Let it be carried for sale to a distance, or let it be converted into cheese and butter, and in this form exported, there will then be a yearly drain upon the land of the materials of bones, from this cause alone, equal to 30 lbs. of bone-dust. After the lapse of centuries, it is conceivable that old pasture lands in cheese and dairy countries should become poor in the materials of bones—and that in such districts, as now in Cheshire, the application of bone-dust should entirely alter the character of the grasses, and renovate the old pastures.

Thus, as was stated at the commencement of the present section the study of the nature, and functions of the food of animals throws additional light upon the nature also and final uses of the food of plants. It even teaches us what to look for in the soil—what a fertile soil *must* contain that it may grow nourishing food—what we must add to the soil when chemical analysis fails to detect its actual presence, or when the food it produces is unable to supply all that the animal requires.

The principles above explained, therefore, shew that the value of any vegetable production, considered as the *sole* food of an animal, is not to be judged of—cannot, in short, be accurately determined—by the amount it may contain of any *one* of those substances, *all* of which together are necessary to build up the growing body of the young animal, and to repair the natural waste of such as have attained to their fullest size.

Hence the failure of the attempts that have been made to support the lives of animals by feeding them upon pure starch or sugar alone. These substances would supply carbon for respiration, but all the natural waste of nitrogen, of saline matter, and of earthy phosphates, must have been drawn from the existing solids and fluids of their living bodies. The animals in consequence pined away, and sooner or later died.

Some have expressed surprise that animals have refused to thrive, and have ultimately died, when fed upon animal jelly or gelatine (from bones) alone, nourishing though that substance *as part of the food* undoubtedly is. When given in sufficient quantity, gelatine might indeed supply carbon enough for respiration, with a great waste of nitrogen, but it is deficient in the saline ingredients which a naturally nourishing food contains.

Even on the natural mixture of starch and gluten in fine white bread, dogs have been unable to live beyond 50 days, though others fed on household bread, containing a portion of the bran —in which earthy matter more largely resides— continued to thrive long after. It is immaterial whether the general quantity of the *whole* food be reduced too low, or whether *one* of its necessary ingredients only be too much diminished or entirely withdrawn. In either case, the effect will be the same—the animal will pine away, and sooner or later die.

SECTION VII.—OF THE PRACTICAL AND THEORETICAL VALUE OF DIFFERENT KINDS OF FOOD.

From what has been stated in the preceding section, it appears, that, for various reasons, different kinds of food are not equally nourishing. This fact is of great importance, not only in the preparation of human food, bnt also in the feeding of stock. It has, therefore, been made the subject of experiment by many practical agriculturists, with the following general results.

If common hay be taken as the standard of comparison, then to yield the same amount of nourishment with 10 lbs. of hay, a weight of the other kinds of food must be given, which is represented by the number opposite to each in the following table :—

Hay, . .	10	Carrots, .	25 to 30
Clover hay, .	8 to 10	Turnips, .	50
Green clover, .	45 to 50	Cabbage, .	20 to 30
Wheat straw, .	40 to 50	Pease and Beans,	3 to 5
Barley straw, .	20 to 40	Wheat, . .	5 to 6
Oat straw, .	20 to 40	Barley, . .	5 to 6
Pea straw, .	10 to 15	Oats, . .	4 to 7
Potatoes, .	20	Indian corn, .	5
Old potatoes, .	40?	Oil cake, .	2 to 4

It is found in practice, as the above table shews, that twenty stones of potatoes or three of oil-cake will nourish an animal as much as ten stones of hay, and five stones of oats as much as either. Something, however, will depend upon the quality of each kind of food, and upon the age and constitution of the animal. The skilful feeder of stock knows also the value of a change of food, or of a mixture of the different kinds of vegetable food he may have at his command.

The nutritive value of different kinds of food has also been represented theoretically, by supposing it to be very nearly in proportion to the quantity of nitrogen, or of gluten, which vegetables contain. Though this cannot be considered as a correct principle, yet as the ordinary kind of food on which stock is fed contains in general an ample supply of carbon for respiration, with a comparatively small proportion of nitrogen, these theoretical determinations are by no means without their value, and they approach in many cases very closely to the practical values above given, as deduced from actual trial. Thus, assuming that 10 lbs. of hay yield a certain amount of nourishment, then of the other vegetable substances it will be necessary, according to theory, to give the following quantities, in order to produce the same effect:

Hay, . .	10	Turnips, . .	60
Clover hay, .	8	Carrots, . .	35
Vetch hay,* .	4	Cabbage, . .	30 to 40
Wheat straw, .	52	Pease and Beans, .	2 to 3
Barley straw, .	52	Wheat, . .	5
Oat straw, .	55	Barley, . .	6
Pea straw, .	6	Oats, . . .	5
Potatoes, .	28	Indian corn, . .	6
Old potatoes,	40	Oil cake, . .	2

If the feeder be careful to supply his stock with a mixture or occasional change of food, he may very safely regulate the quantity of any one he ought to substitute for a given weight of any of the others, by the numbers in the above tables—since the theoretical and practical results do not in general very greatly differ.

As has been already stated, it is not strictly correct that this or that kind of vegetable is more fitted to sustain animal life, simply because of the larger proportion of nitrogen it contains; but it is wisely provided, that along with this nitrogen in all plants, a certain proportion of starch or

* Both cut in flower.

sugar and of saline and earthy matter are always associated—so that the quantity of nitrogen may be considered as a rough practical index of the proportion of some of the important saline and earthy ingredients also.

An important practical lesson on this subject is taught us by the study of the wise provisions of Nature. Not only does the milk of the mother contain all the elements of a nutritive food mixed up together—as the egg does also for the unhatched bird—but in rich natural pastures the same mixture uniformly occurs. Hence, in cropping the mixed herbage, the animal introduces into its stomach portions of various plants—some abounding more in starch or sugar, some more in gluten or albumen, some naturally richer in saline, others in earthy constituents; and out of these varied materials the digestive organs select a due proportion of each, and reject the rest. Wherever a pasture becomes usurped by one or two grasses—either animals cease to thrive upon it, or they must crop a much larger quantity of food to supply the natural waste of *all* the parts of their bodies.

It may indeed be assumed as almost a general principle, that whenever animals are fed on one kind of vegetable only, there is a waste of one or other of the necessary elements of animal food, and that the great lesson on this subject taught us by nature is, that, by a judicious admixture, not only is food economised, but the labour imposed upon the digestive organs is also materially diminished.

SECTION VIII.—CONCLUDING OBSERVATIONS.

In this little work, now brought to a close, I have presented the reader with a slight, and I hope plain and familiar, sketch of the various topics connected with practical agriculture, on which the sciences of chemistry and geology are fitted to throw the greatest light.

We have studied the general characters of the organic and inorganic elements of which the parts of plants are made up, and the several compounds of these elements which are of the greatest importance in the vegetable kingdom. We have examined the nature of the seed,—seen by what beautiful provision it is fed during its early germination—in what form the elements by which it is nourished are introduced into the circulation of the young plant when the functions of the seed are discharged,—and how earth, air, and water are all made to minister to its after-growth. We have considered the various chemical changes which take place within the growing plant, during the formation of its woody stem, the blossoming of its flower, and the ripening of its seed or fruit,—and have traced the further changes it undergoes, when, the functions of its short life being discharged, it hastens to serve other purposes, by mingling with the soil, and supplying food to new races. The soils themselves in which plants grow, their nature, their origin, the causes of their diversity in mineral character, and in natural productiveness, have each occupied a share of our attention—while the various means of improving their agricultural value by manuring or otherwise, have been practically considered, and theoretically explained. Lastly, we have glanced at the comparative worth of the various products of the land, as food for man or other animals, and have briefly illustrated the principles upon which the feeding of animals and the relative nutritive powers of the vegetables on which they live are known to depend.

In this short and familiar treatise I have not sought so much to *satisfy* the demands of the philosophical agriculturist, as to *awaken* the curiosity of my less instructed reader, to shew him how much interesting as well as practically useful information chemistry and geology are able and willing to impart to him, and thus to allure him in quest of further knowledge and more accurate details to my larger work,* of which the present exhibits only a brief outline.

* LECTURES *on Agricultural Chemistry and Geology.*

J. P. Wright, Printer, 18 New street, N. Y.