LECTURES

ON

AGRICULTURAL CHEMISTRY,

DELIVERED BEFORE THE SENIOR CLASS

OF THE

UNIVERSITY OF GEORGIA,

BY JOHN LECONTE, M. D.,

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FRANKLIN COLLEGE, Oct. 23d, 1847.

SIR—We have been appointed a committee by the Senior Class to tender you their sincere thanks for the politeness and respect you have on all occasions manifested towards them, and also to solicit for publication copies of your Lectures on Agricultural Chemistry, read before them on the evenings of the 21st and 22d instant.

Ardently desiring that you will comply with our request, we return you the highest esteem of the Class and the warmest regard of

Your humble servants,

W. D. WILLIAMS,
J. M. TILLEY,
F. R. TARVER,
B. A. THORNTON,

Committee.

Dr. Jno. LeCONTE.

ATHENS, Oct. 25th, 1847.

GENTLEMEN—In reply to your communication of the 23d instant, in behalf of the Senior Class, I beg that you would return to the members of the Class my warmest acknowledgments for the uniform respect and attention they have shown me, and for the very flattering manner in which they have seen fit to express themselves.

Under the circumstances, I feel bound to place the Lectures referred to at the disposal of the Class; although they contain nothing that is new, or that is not accessible to those who have kept pace with the advancement of this department of Science.

With sentiments of the highest esteem, I remain yours, very truly,

To Messrs. W. D. WILLIAMS,
J. M. TILLEY,
F. R. TARVER,
B. A. THORNTON,

Committee.

JOHN LeCONTE.
Lecture I.

The most careless observer cannot fail to recognize in the world around him, many evident distinctions between living beings and inanimate objects. Perhaps the most apparent and permanent of these distinctions is based rather upon a comparison of their mode of existence, than upon any examination of their intimate structure. The ceaseless tendency to change, manifested in the life of the former, stands in yet more obvious contrast with the unaltering stability of the latter. The snow-capped mountain rears its summit to the clouds, unaffected by the lapse of the ages which have rolled by since its first elevation—a monument of Nature's power; and the giant edifices erected by the hand of man on the plains of Egypt, bear to remote posterity the attestation of the former grandeur of a nation now sunk in poverty and insignificance. And what, compared with the permanence of these, is the duration of any structure subject to the conditions of vitality? "To be born, to grow, to arrive at maturity, to decline, to die, to decay, is the sum of the history of every being that lives, from man in the pomp of royalty or the pride of philosophy, to the gay and thoughtless insect that glitters for a few hours in the sunbeam and is seen no more; from the stately oak, the monarch of the forest through successive centuries, to the humble fungus which shoots forth and withers in a day. And yet, amidst the constant change and succession of individuals, we observe the form and character first impressed upon each race by the Creator of all, uninterruptedly transmitted from parent to offspring through periods of indefinite duration. "One generation passeth away"—but "another cometh"—like it in structure, functions, habits, food, instincts, passions, and the limit of its existence. The mistletoe flourishes on the oak of the English forests, just as when made an object of superstitious veneration in the hallowed groves of the Druids. The bee builds her comb with the same unvarying regularity, and stores it with the same materials now, as when her beautiful works attracted the
notice of the poets and philosophers of classic ages. And man, however modified by education, however various his degree of civilization, however elevated his condition of mental-and moral refinement, is yet born the same helpless dependent being, with the same dormant faculties of body and mind, as the first offspring of our original parents.

In the ever-varying conditions of the animated world, then, a very superficial glance will display to us a certain degree of regularity and arrangement; and the more attentively we investigate the relations which its changes present, the more stable and definite is the assurance we obtain, that they are all harmonized and controlled by fixed laws, which are but simplified expressions of those conditions of action which the Creator has imposed upon organized no less than inorganic matter. To arrive at a knowledge of these laws, and, having attained them, to trace their application to all the countless variety of phenomena presented by the myriads of living beings whose beautiful forms people this globe, is the object of the science of Physiology—the science of life—using that term in its most extended sense. Only a part of this immense field of investigation appropriately belongs to the chemist. "The object of organic chemistry is to discover the chemical conditions which are essential to the life and perfect development of animals and vegetables, and, generally, to investigate all those processes of organic nature which are due to the operation of chemical laws."—Liebig.

I propose, on this occasion, to take a rapid and cursory survey of a few of the discoveries which chemistry has furnished within the last 6 or 8 years, viewed in their relation to agriculture. During the last few months, you have learnt that, all the material substances in nature consist of one or more of 55 or 60 elementary bodies. This is sufficiently surprising, yet it is, if possible, still more remarkable that nearly the entire mass of every vegetable and animal substance may be resolved into one or more of four only of these simple substances. I say nearly the entire mass, because inorganic matters do enter into the constituents of both animals and vegetables, and are essential to their perfect development; but they constitute but a comparatively small portion of their bulk. When a portion of animal or vegetable matter is burned, it either entirely disappears or leaves behind it only a small quantity of ashes. Now all that disappears in this process, generally consists of 4 elementary bodies, viz: carbon, oxygen, hydrogen and
nitrogen. To the agriculturist, therefore, an acquaintance with these 4 constituent parts of all that lives and grows on the face of the globe, is absolutely indispensable. It is impossible for him to comprehend the laws by which the operations of nature in the vegetable kingdom are conducted, or the reason of the processes he himself adopts in order to facilitate or to modify these operations, without this previous knowledge of the nature of the elements—the raw materials as it were, out of which all the products of vegetable growth are elaborated.—Johnston's Lectures on Agricultural Chemistry.

Presuming that you have a sufficient general acquaintance with these organic elements, we will pass on immediately to the subject of Agriculture.

Agriculture is both a science and an art. The knowledge of all the conditions of the life of vegetables, the origin of their elements, and the sources of their nourishment, forms its scientific basis. From this knowledge we derive certain rules for the exercise of the art, the principles upon which the mechanical operations of farming depend, the usefulness or necessity of these for preparing the soil to support the growth of plants, and for removing every obnoxious influence. No experience, drawn from the exercise of the art, can be opposed to true scientific principles, because the latter should include all the results of practical operations, and are in some instances solely derived therefrom. Theory must correspond with experience, because it is nothing more than a reduction of a series of phenomena to their last causes. A field in which is cultivated the same plant for several successive years, becomes barren for that plant in a period varying with the nature of the soil: in one field it will be in 3, in another in 7, in a third in 20, in a fourth in 100 years. One field bears wheat, and no peas; another beans and turnips, but no tobacco; a third gives a plentiful crop of turnips, but will not bear clover. What is the reason that a field loses its fertility for one plant, the same which at first flourished there? What is the reason one kind of plant succeeds in a field where another fails? These questions belong to science. What means are necessary to preserve to a field its fertility for one and the same plant? What to render one field fertile for two, for three, for all plants? These last questions are put by art, but they cannot be answered by art. If a farmer, without the guidance of just scientific principles, is trying experiments to render a field fertile for a plant which it otherwise will
not bear, his prospect of success is very small. Thousands of farmers try such experiments in various directions, the result of which is a mass of practical experience forming a method of cultivation which accomplishes the desired end for certain places; but the same method does not succeed—it indeed ceases to be applicable to a 2d or 3d place in the immediate neighborhood. How large a capital, and how much power, are wasted in these experiments! Very different, and far more secure, is the path indicated by science; it exposes us to no danger of failing, but, on the contrary, it furnishes us with every guarantee of success. If the cause of failure, of barrenness in the soil for one or two plants, has been discovered, means to remedy it may readily be found.—Liebig's Letters.

The most exact observations prove that the method of cultivation must vary with the geological condition of the subsoil. In basalt, porphyry, sandstone, limestone, etc., are certain elements indispensable to the growth of plants, and the presence of which renders them fertile. This fully explains the difference in the necessary methods of culture for different places; since it is obvious that the essential elements of the soil must vary with the varieties of composition of the rocks, from the disintegration of which they originated. Wheat, corn, clover, turnips, for example, each require certain elements from the soil; they will not flourish where the appropriate elements are absent. Science teaches what elements are essential to every species of plant by an analysis of their ashes. If, therefore, a soil is found wanting in any of those elements, we discover at once the cause of its barrenness, and its removal may now be readily accomplished. The empiric attributes all his success to the mechanical operations of agriculture; he experiences and recognises their value, without inquiring what are the causes of their utility, their mode of action: yet this scientific knowledge is of the highest importance for regulating the application of power and the expenditure of capital—for insuring its economical expenditure and the prevention of waste. Can it be imagined that the mere passing of the ploughshare or the harrow through the soil—the mere contact of iron—can impart fertility miraculously? Nobody perhaps, seriously entertains such an opinion. Nevertheless, the modus operandi of these mechanical operations is by no means generally understood. The fact is quite certain, that careful ploughing exerts the most favorable influence: the surface is thus mechanically divided, changed, increased,
and renovated; but the ploughing is only auxiliary to the end sought. In the effects of time, in what in Agriculture are technically called fallows—the repose of the fields—we recognise by science certain chemical actions, which are continually exercised by the elements of the atmosphere upon the whole surface of the globe. By the action of its oxygen and its carbonic acid, aided by water, rain, changes of temperature, etc., certain elementary constituents of rocks, or of their ruins, which form the soil capable of cultivation, are rendered soluble in water, and consequently become separable from all their insoluble parts. These chemical actions, poetically denominated the "tooth of time," destroy all the works of man, and gradually reduce the hardest rocks to the condition of dust. By their influence the necessary elements of the soil become fitted for assimilation by plants; and it is precisely the end which is obtained by the mechanical operations of farming. They accelerate the decomposition of the soil, in order to provide a new generation of plants with the necessary elements in a condition favorable to their assimilation. It is obvious that the rapidity of the decomposition of a solid body must increase with the extension of its surface; the more points of contact we offer in a given time to the external chemical agent, the more rapid will be its action. The chemist, in order to prepare a mineral for analysis, to decompose it, or to increase the solubility of its elements, proceeds in the same way that the farmer deals with his fields—he spares no labor in order to reduce it to the finest powder; he separates the impalpable from coarser parts by washing, and repeats his mechanical bruising and trituration, being assured his whole process will fail if he is inattentive to this essential and preliminary part of it.—Liebig's Letters.

Having spoken of some of the general principles, let me now direct your attention to some of those particulars which will more forcibly exhibit the connection between chemistry and agriculture, and demonstrate the impossibility of perfecting the important art of rearing food for man and animals without considerable knowledge of our science. It has already been remarked, that the great mass of organic matter consists of only four elementary bodies, viz: carbon, oxygen, hydrogen, and nitrogen. An important question naturally arises, namely: from what source do plants derive these elements? And first, of carbon. I presume it will be conceded that carbon is incapable of entering directly, in its solid state, into the circulation of plants; since
solid substances of every kind are unfit for being taken up
by the organs of plants. Carbon, therefore, must enter ei-
ther in the gaseous or liquid form, but from what source
must it be derived? There are but two sources from which
it can be obtained—the soil in which the plant grows—and
the air by which its stem and leaves are surrounded. In
the soil much vegetable matter is often present, and the
farmer adds vegetable manure in large quantities with the
view of providing food for his intended crop. Are plants
really fed by the vegetable manure that is added to it? This question has an important practical bearing. Let us,
therefore, submit it an examination.

1st. We have the most conclusive and satisfactory geological evidence, that there was a time when no vegetable
matter existed in the soil which overspread the earth's sur-
face. The first plants must have grown without the aid of
either animal or vegetable matter—that is, they must have
been nourished from the air.

2d. It is known that certain marly soils, raised from
a great depth beneath the surface, and containing no veg-
etable matter, will yet, without manure, yield luxuriant
crops. Islands upheaved from the bottom of the ocean by
subaqueous volcanic action, soon become clothed with veg-
etation. The carbon in such cases must also have been
derived from the air.

3d. You know that some plants grow and increase in size
when suspended in the air, and without being in contact
with the soil. You know, also, that many plants—bulbous
flower-roots for example—will grow and flourish in pure
water only, provided they are open to the access of the at-
mospheric air. Seeds also will germinate, and when daily
watered, will rise into plants, though sown in substances
that contain no trace of vegetable matter. These facts have
been established experimentally by MM. De Saussure and
Boussingault. The source of carbon in these cases cannot
be doubted.

4th. When lands are impoverished, they are laid down
to grass, and the longer they lie undisturbed the richer in
vegetable matter does the soil become. When broken up,
a black fertile mould is found where little trace of organic
matter had previously existed. The same observation ap-
plies to lands long under wood. The vegetable matter in-
creases, the soil improves, and cleared and ploughed it
yields abundant crops of corn. Do grasses and trees de-
rive their carbon from the soil? Then, how, by their
growth, do they increase the quantity of carbonaceous matter which the soil contains? It is obvious that, taken as a whole, they must draw from the air not only as much as is contained in their own substance, but an excess also, which they impart to the soil.

5th. But on this point, the rapid growth of peat may be considered as absolutely conclusive. A tree falls across a little running stream, dams up the water, and produces a marshy spot. Rushes and reeds spring up, mosses take root and grow. Year after year new shoots are sent forth and the old plants die. Vegetable matter accumulates; a bog, and finally a thick bed of peat is formed. Whence have these plants derived their carbon? The quantity originally contained in the soil is, after a lapse of years, increased 10,000 fold. Has dead matter the power of reproducing itself? You will answer at once, that all these plants must have grown at the expense of the air, must have lived on the carbon it was capable of affording them, and as they died must have left this carbon in a state unfit to nourish the succeeding races. This reasoning appears unobjectionable, and, from the entire group of facts, we seem justified in concluding that plants every where, and under all circumstances, derive the whole of their carbon from the atmosphere.—Johnston.

I shall not pause to point out the limitation of this inference—that under certain circumstances the soil does not cooperate with the air in furnishing this element; it is sufficient for our purpose to have established the fact, that plants derive the greater portion of their carbon from the atmosphere. Various experiments and observations prove conclusively, that this carbon enters plants in the form of carbonic acid. You are aware that this gas is an invariable constituent of the atmosphere; thus vegetables are furnished with an inexhaustible supply of this element.

The source of the oxygen and the hydrogen of plants is less doubtful, and will require less illustration than that of carbon. Water is a well-known compound of these two elements. In the form of aqueous vapor, this compound pervades the atmosphere, and plays among the leaves of plants, while in the liquid state, it is diffused through the soil, and is unceasingly absorbed by the roots of all living vegetables. Hydrogen is also contained in ammonia, and oxygen enters into the composition of carbonic acid, besides being a large constituent of the air itself. From these
atmospheric sources, it is obvious that an ample supply of oxygen and hydrogen is afforded to plants.

Finally, it has been abundantly shown by Liebig, Dumas, Boussingault, and others, that the remaining element, nitrogen, is likewise furnished from the atmosphere in the forms of ammonia and nitric acid. Hence it follows, that the atmosphere contains all the elements which form the great mass of organic structures, and that too, in a form fitted for the assimilation of vegetables. But if the atmosphere furnishes every thing essential to organization, why, it may be reasonably asked, is so much attention paid to the preparation of the soil and to manuring? Is the agricultural experience of all ages and of all countries to be at once rejected, or are we to modify our views? We here touch upon a point which is of vast importance to the practical agriculturist.

It has been previously hinted, that, in addition to the four organic elements which form the bulk of vegetables, there are certain inorganic substances, which, although existing in small quantities, play a most important part in their economy. It cannot be doubted that the inorganic constituents contained in the ashes are really essential parts of the substance of plants—that they cannot live a healthy life or perfect all their parts without them—and that it is the duty of the husbandman to supply them when they are wanting in the soil. In the vast aerial ocean which envelops our planet, the beneficent Creator has furnished an inexhaustible supply of the raw materials which are required for the development of organized structures; but unless the proper machinery and tools are supplied, these materials cannot be made to assume an available form. Every plant receives, by means of the water taken up by the roots, certain soluble alkalies, alkaline earths and phosphates, which are necessary to its organization. If these elements be wanting, its growth is retarded. In fact, the development of the plant is in a direct ratio to the amount of matters which it takes up from the soil. If, therefore, a soil is deficient in these mineral constituents, required by plants, they will not flourish, even with an abundant supply of every thing else. We have already seen, that the produce of carbon is independent of a supply of carbonaceous manure, but it depends upon the presence of certain elements in the soil which in themselves contain no carbon, together with the existence of conditions under which their assimilation by plants can be effected. We increase the
produce of our cultivated fields, in carbon, by supplying lime, ashes and marl, substances which cannot furnish carbon to the plants, and yet it is indisputable, being founded upon abundant experience, that in these substances we furnish to the fields elements which greatly increase the bulk of their produce, and consequently the amount of carbon. If we admit these facts to be established, we can no longer doubt that a deficient produce of carbon, or in other words, the barrenness of a field does not depend upon carbonic acid, because we are able to increase the produce, to a certain degree, by a supply of substances which do not contain any carbon.—Liebig's Letters.

The great object of agriculture, therefore, is to discover the means best adapted to enable these plants to assimilate the carbon of the atmosphere which exists in it as carbonic acid. In furnishing plants, therefore, with mineral elements we give them the power to appropriate carbon from a source which is inexhaustible; while in the absence of these elements, the most abundant supply of carbonic acid, or of decaying vegetable matter, would not increase the produce of the field.

As has already been remarked, all plants require for their healthy sustenance the alkalies and alkaline earths, each in a certain proportion; and in addition to these, the cerealia, such as corn, rice, wheat, barley, rye, oats, etc., do not succeed in a soil destitute of silica in a soluble condition, as it forms the framework of their stems and leaves. The combinations of this substance found as natural productions, namely, the silicates, differ greatly in the degree of facility with which they undergo decomposition, in consequence of the unequal resistance opposed by their integral parts to the dissolving power of the atmospheric agencies. Thus, the granite from certain localities degenerates into a powder in a time which scarcely suffices to deprive other kinds of their polish. Some soils abound in silicates so readily decomposable, that every one or two years, as much silicate of potash becomes soluble and fitted for assimilation as is required by the leaves and straw of a crop of wheat. In Europe, particularly in Hungary, extensive districts are not uncommon where wheat and tobacco have been grown alternately upon the same soil for centuries, the land never receiving back any of those mineral elements which were withdrawn in the grain and straw. On the other hand, there are fields in which the necessary amount of soluble silicate of potash for a single crop of wheat is not separated
from the insoluble masses in the soil in less than two, three, or even more years. The term fallow, in Agriculture, designates that period in which the soil, left to the influence of the atmosphere, becomes enriched with those soluble mineral constituents. Fallow, however, does not generally imply an entire cessation of cultivation, but only an interval in the growth of the cereal. That store of silicates and alkalies which is the principal condition of their success, is obtained, if potatoes or turnips are grown upon the same fields in the intermediate periods, since these crops do not abstract a particle of silicate, and therefore leave the field equally fertile for the following crop of wheat.—Liebig.

From the preceding remarks it is obvious, that the mechanical working of the soil is the simplest and cheapest method of rendering the elements of nutrition contained in it accessible to plants. But it may be asked, are there not other means of decomposing the soil besides its mechanical subdivision? Are there not substances, which by their chemical operation shall equally well, or better, render its constituents suitable for entering into vegetable organisms? Yes, we certainly possess such substances, and one of them, namely, quicklime, has been employed for the last century in England for this purpose. In order to obtain correct views respecting the effect of quick lime upon the soil, let me remind you of the process employed by the chemist when he wishes to bring the elements of a mineral into a soluble state. Let the mineral to be examined be, for instance, feldspar; this substance, even when reduced to the finest powder, requires for its solution to be treated with an acid for weeks or months; but if we first mix it with quicklime, and expose the mixture to a moderately strong heat, the lime enters into chemical combination with certain elements of the feldspar, and its alkali (potassa) is set free. And now the acid, even without heat, dissolves not only the lime, but also so much of the silica of the feldspar as to form a transparent jelly. The same effect which the lime in this process, with the aid of heat and acid, exerts upon the feldspar, it produces when it is mixed with the alkaline argillaceous or clayey silicates, and they are for a long time kept together in a moist state.—Idem.

A no less favorable influence than that of lime, is exercised upon the soil of peaty land by the mere act of burning it; this greatly enhances its fertility. In their natural state, potter's-clay, pipe-clay, loam, and many different modifications of clay, may be boiled in concentrated sulphu-
anic acid without sensible change; but if freely burned, they dissolve in the acid with the greatest facility. These kinds of clay belong to the most sterile soils, and yet it contains within itself all the constituent elements essential to a most luxuriant growth of plants; but their mere presence is insufficient to secure this end. The soil must be accessible to the atmosphere, to its oxygen, to its carbonic acid; these must penetrate it, in order to secure the conditions necessary to a happy and vigorous development of the plant. The elements present must be brought into that peculiar state of combination which enables them to enter into vegetables. Clay is often wanting in these properties; but they are imparted to it by teebie calcination.—**Liebig.**

These facts explain in a satisfactory manner, the favorable influence which *marl* and ashes exert upon most soils. The cerealia require the alkalies and alkaline silicates, which the action of the lime, marl, or ashes, renders fit for the assimilation of the plants. If, in addition to these, there is any decaying organic matter present in the soil, supplying carbonic acid, it may facilitate their development, but it is not essential to their growth. If we furnish the soil with ammonia, and the phosphates, which are indispensable to the cerealia, with the alkaline silicates, we have all the conditions necessary to insure an abundant harvest. The atmosphere is an inexhaustible store of carbonic acid.—**Idem.**

I have now to make a few remarks on the uses and effects of animal and vegetable manures, properly so called. In order to understand the nature of these, and the peculiarity of their influence upon our fields, it is highly important to keep in mind the source whence they are derived. It is well known, that during the life of an animal every part of its living substance is undergoing a perpetual change; all its component parts, assuming the form of lifeless compounds, are thrown off by the skin, lungs, and urinary system, altered more or less by the secretory organs. Observation and chemical analysis teach us, that the carbon, oxygen, and hydrogen of the blood, of the muscular fibre, and of all the animal tissues which can undergo change, return into the atmosphere, through the skin and lungs, in the form of carbonic acid and water. The nitrogen, and all the soluble inorganic elements, are carried to the earth in the urine. These changes take place in the healthy animal body during every moment of life; a waste and loss of substance proceeds continually; and if this loss is to be restored, and the original weight and substance repaired, an
adequate supply of materials must be furnished whence the blood and wasted tissues may be regenerated. This supply is obtained from the food. In an adult person in a healthy condition, no sensible increase or decrease of weight occurs from day to day. In youth the weight of the body increases, while in old age it decreases. There can be no doubt that in the adult, the food has exactly replaced the loss of substance: it has supplied just so much carbon, hydrogen, nitrogen, and other elements, as have passed through the skin, lungs and urinary organs. In youth the supply is greater than the waste. Part of the elements of the food remain to augment the bulk of the body. In old age the waste is greater than the supply, and the body diminishes. It is unquestionable, that, with the exception of a certain quantity of carbon and hydrogen, which are secreted by the skin and lungs, we obtain, in the solid and fluid excrements of man and animals, all the elements of their food. Thus we see, that all the constituent ingredients of the consumed food, soluble and insoluble, are returned; and as food is primarily derived from the fields, we possess in those excrements all the ingredients which we have taken from it in the form of seeds, roots, or herbs. One part of the crops employed for fattening sheep and cattle, is consumed by man as animal food; another part is taken directly—as flour, potatoes, corn, rice, green vegetables, etc.; a third portion consists of vegetable refuse, and straw employed as litter. None of the materials of the soil need be lost. We can, it is obvious, get back all its constituent parts which have been withdrawn therefrom, as fruits, grain and animals, in the fluid and solid excrements of man, and the bones, blood and skins of the slaughtered animals. It depends upon ourselves to collect carefully all these scattered elements, and to restore the disturbed equilibrium of composition in the soil. We can calculate exactly how much and which of the components of the soil we export in a sheep or an ox, in a bushel of corn, wheat, or potatoes, and we can discover, from the known composition of the excrements of man and animals, how much we have to supply to restore what is lost to our fields.—Liebig’s Letters.

The principal problem for agriculture is, how to replace those substances which have been taken from the soil, and which cannot be furnished by the atmosphere. If the manure supplies an imperfect compensation for this loss, the fertility of a field or of a country decreases; if, on the contrary, more are given to the fields, their fertility increases.
An importation of urine, or of solid excrements, as guano, from a foreign country, is equivalent to an importation of grain and cattle. In a certain time, the elements of those substances assume the form of grain, or of fodder, then become flesh and bones, enter into the human body, and return again day by day to the form they originally possessed. The only real loss of elements we are unable to prevent, is of the phosphates, and these, in accordance with the customs of all modern nations, are deposited in the grave.—For the rest, every part of that enormous quantity of food which a man consumes during his lifetime, (say 60 or 70 years,) which was derived from the fields, can be obtained and returned to them.—Idem.

You will now understand that the constituents of the solid parts of animal excrements, and therefore their qualities as manure, must vary with the nature of the creature’s food. If we feed a cow upon turnips, or potatoes, without hay, straw, or grain, there will be no silica in solid excrements, but there will be phosphate of lime and magnesia. In one word, the excrements of the animal must contain all the constituent elements of food, and therefore are best suited to manure the vegetables which it consumed. The excrements of animals which have been fed on peas and potatoes are principally suited for manuring crops of peas and potatoes; of those which have been fed on corn and oats, for manuring corn and oats.—Idem.

It is obvious, therefore, that the art of rational agriculture, must be based upon the restitution of a disturbed equilibrium. Can it be imagined that any country, however rich and fertile, with a flourishing commerce, which for centuries exports its produce in the shape of grain and cattle, will maintain its fertility, if the same commerce does not restore, in some form of manure, those elements which have been removed from the soil, and which cannot be replaced by the atmosphere? Must not the same fate await every such country which has actually befallen the once prolific soil of Virginia, now in many parts no longer able to grow its former staple productions—wheat and tobacco?—Liebig.

When a country is thinly peopled, like the newly settled districts of the United States and the greater portion of our state, a very defective system of culture will produce food enough not only for the wants of the inhabitants, but for the partial supply of other countries also. But when the population becomes more dense, the same imperfect or slug-
lish system will no longer suffice. The land must be better tilled, its special defects must be studied, and means must gradually be adopted for extracting the maximum produce from every portion susceptible of cultivation. As the population of a country continues to increase, it is an important question to determine whether the food raised from the land will continue to augment in the same ratio. In this country, the population is too sparse to furnish the means of making any estimate on this point. With regard to England our data are more definite. The superficial area of Great Britain comprises about 57 millions of acres, of which, in 1840, 34 millions were in cultivation, about 13 millions were incapable of culture, and the remaining 10 millions were waste lands susceptible of improvement. The population in 1840—or 20 millions—were, therefore, supported by the produce of 34 millions of acres; or every 34 acres raised food for about 20 people. Suppose the 10 millions of acres which are susceptible of improvement, to be brought into such a state of culture as to maintain an equal proportion—the most favorable supposition—they would raise food for an additional population of 6 millions, or would keep Great Britain independent of any large and constant foreign supply till the number of its inhabitants amounted to 26 millions. But at the present rate of increase, this will take place in about 20 years from 1840, so that by 1860, unless some general improvement take place in the agriculture of the country, the demands of the population will have completely overtaken the productive powers of the land.—Johnston.

But when we consider the rapid advancement of this department of science, it is impossible to predict or foresee the exact limit of the productive powers of a country, although, it is obvious, that there must be a limit to it.

In the large towns of England, as also of this country, a large quantity of the elements of the soil indispensable to plants do not return to the fields. By contrivances resulting from the manners and customs of the people, an enormous quantity of the phosphates, are daily carried into the rivers, in the form of solid and liquid excrements. Hence, in England, it has become necessary to import bones to restore this loss. At present, the importation of bones for manure amounts in value to upwards of a million of dollars per annum, but it is far from being sufficient to supply the waste. It has been estimated, that if it were possible to restore to the soil of England and Scotland the phosphates
which during the last 50 years have been carried into the sea by the Thames and the Clyde, it would be equivalent to manuring with millions of tons of bones, and the produce of the land would increase one-third, or perhaps, double itself, in 5 or 10 years.—*Liebig's Letters*.

When we have exactly ascertained the quantity of ashes left after the combustion of cultivated plants which have grown upon all varieties of soil, and have obtained correct analyses of these ashes, we shall learn with certainty which of the constituent elements of the plants are constant and which are changeable, and we shall arrive at an exact knowledge of the sum of all the ingredients we withdraw from the soil in the different crops. With this knowledge the farmer will be able to keep an exact record of the produce of his fields in harvest, like the account-book of a well-regulated manufactory; and then by a simple calculation he can determine precisely the substances he must supply to each field, and the quantity of these, in order to restore their fertility. He will be able to express, in pounds weight, how much of this or that element he must give to the soil in order to augment its fertility for any given kind of plants. These researches and experiments are the great *desiderata* of the present time. To the united efforts of the chemists of all countries we may confidently look for a solution of these great questions, and by the aid of enlightened agriculturists we shall arrive at a rational system of gardening, horticulture, and agriculture, applicable to every country and all kinds of soil, and which will be based upon the immutable foundation of observed facts and philosophical induction.—*Idem*. 
Plants, as we have seen in a former Lecture, derive much of their sustenance from the carbonic acid of the atmosphere; yet of this gas the air contains only a very small fraction, and in so far as experiments have yet gone, this fractional quantity does not appear to diminish. How, then, it may be asked, is the supply of carbonic acid kept up? Again, plants most probably obtain much of their nitrogen either from ammonia or from nitric acid; and yet, neither in the soil nor in the air do these compounds permanently exist in any notable quantity. Whence then is the supply of these substances brought within the reach of plants? The importance of these two questions will appear more distinctly, if we endeavor to estimate how much of their carbon plants really draw from the air by which they are surrounded. It is necessary that you should understand the principle on which they were conducted, in order that you may be prepared to place confidence in the determinations at which he arrived. If we were to examine the soil of a field on which we are about to raise a crop of corn—and should find it to contain a certain per centage, say 10 per cent of vegetable matter, or 5 per cent of carbon; and after the crop is raised and reaped, should, on a second examination, find it to contain exactly the same quantity of carbon as before, we could not resist the conviction, that, with the exception of what was originally in the seed, the plant during its growth had drawn from the air all the carbon it contained. The soil having lost none, the air must have yielded the whole supply. Or if, after examining the soil of our field, we mix with it a supply of farm-yard manure,
containing a known weight, say one ton, of carbon, and when the crop is reaped, find as before, that the per centage of vegetable matter in the soil has suffered no diminution, we are justified in concluding that the crop cannot, at the utmost, have derived from the soil any greater weight of its carbon than the ton contained in the manure which had been added to it.—Boussingault's Rural Economy.

Such was the principle on which Boussingault’s experiments were conducted. He determined the per centage of carbon in the soil before the experiment was begun—the weight added in the form of manure—the quantity contained in the series of crops—and lastly, the proportion of carbon remaining in the soil. By this method he found, that an acre of land supplied with manure containing 2513 pounds of carbon, produced 7544 pounds of carbon in the crops, making the difference, or amount of carbon derived from the air 5931 pounds. The crops collected contained three times the quantity of carbon present in the manure, and therefore, the plants, during their growth, must on the whole have derived two-thirds of their carbon from the air. It is fair to assume that a considerable portion of the carbon of the manure and of the soil would naturally escape and be lost, and that, therefore, the proportion of carbon derived from the air in Boussingault’s experiments, must have been really considerably greater than is indicated by the numerical results. However, let two-thirds of the entire quantity of carbon contained in a series of crops be taken as the average proportion which must be derived from the air in the form of carbonic acid—and let the average weight of the dry crop reaped be estimated at one and a half tons per acre. Then, if the crop contain half its weight of carbon, the plants grown on each acre must annually extract from the air 10 cwt. or 1120 pounds of carbon in the form of carbonic acid.—Johnston’s Lectures.

But the question will here at once suggest itself to you—does not the quantity thus extracted from the air really form a very large proportion of the whole weight of carbon which is contained in the atmosphere? A simple calculation will give us clear ideas in regard to this interesting point. The admirable researches of De Saussure show, that the average quantity of carbonic acid in the atmosphere of our globe may be estimated at about \( \frac{4}{10000} \) or \( \frac{2}{2500} \) part of its entire bulk. This is equal very nearly to \( \frac{7}{3000} \) of its weight. Or taking the whole weight of the atmosphere at fifteen pounds on the square inch—that of the carbonic
acid will be 0.009 lbs. or 63 grains per square inch. But as the carbonic acid contains only twenty-seven and two-third per cent of its weight of carbon, the weight of this element which presses on each square inch of the earth's surface is only 17.39 grains. Upon an acre, therefore, this amounts to 7 tons. But if the crop on each acre of cultivated land annually extracts from the air half a ton of carbon, the whole of the carbonic acid in the atmosphere would sustain such a vegetation over the entire globe for fourteen years only. And if we even suppose such a vegetation to extend over one-hundredth of the earth's surface, it still appears sufficient to exhaust the carbonic acid of the air in fourteen hundred years. A very short period, compared even with the limits of authentic history, has yet elapsed since experience began to be made on the true constitution of the atmosphere; we have no trustworthy data, therefore, on which to found a confident opinion in regard to the permanence of the proportion of carbonic acid which it now contains. But the recorded identity of all the phenomena of vegetation renders it probable that the proportion has not sensibly diminished even within historic times.—Idem.

From what sources, then, is the supply of carbonic acid in the atmosphere kept up? And if the proportion be permanent, by what compensating processes is the quantity which is restored to the atmosphere produced and regulated? You are all aware, that all the rain which falls as well as the watery vapor actually present in the air, may fall in the form of rain or dew and ascend again in vapor several successive times in a single year. Is it so also with the carbon in the air? Does that which feeds the growing plant to-day, again mount up in the form of carbonic acid at some future time, ready to minister to the sustenance of new races, and to run against the same round of ever-varying change? Such is, indeed, the general history of the agency of the carbonic acid of the atmosphere; but when once it has been fixed in the plant it must pass through many successive changes before it is again set free. The conditions, also, under which it is restored to the atmosphere are so diversified—and the agencies by which, in each case, it is liberated are so very distinct, as to require that the several modes by which the carbon of plants is reconverted into carbonic acid and returned to the air, should be made topics of separate consideration. And 1st, on the production of carbonic acid by the respiration of animals. The air we breathe when it is drawn into the lungs, con-
tains \frac{1}{2500} th of its bulk of carbonic acid; when it returns again from the lungs, the bulk of this gas amounts, on an average, to one twenty-fifth of the whole; or its quantity is increased one hundred times. The actual bulk of the carbonic acid emitted from the lungs of a single individual in twenty-four hours varies exceedingly; it has been estimated, however, on an average, to contain upwards of five ounces of carbon. A full grown man, therefore, gives off from his lungs, in the course of a year, upwards of one hundred pounds of carbon in the form of carbonic acid. If the quantity of carbon thus evolved from the lungs be in proportion to the weight of the animal, a cow or a horse ought to give off 6 times as much as a man. From indirect experiments, M. Boussingault estimated the actual quantity of carbon lost in this way by a cow and a horse, at six or seven times the amount given off from the lungs of a man. If we suppose each inhabitant of the United States, young and old, to expire only eighty pounds of carbon a year, the twenty millions would emit seven hundred thousand tons; and, allowing the cattle, sheep, and all other animals, to give off twice as much more, the whole weight of carbon returned to the air by respiration in this country would be about two millions of tons, or the quantity abstracted from the atmosphere by four millions of acres of cultivated land. Extending the same calculation to the whole animal population of the globe, it appears, that upwards of one hundred millions of tons of carbon is annually supplied to the atmosphere through the medium of respiration; an amount sufficient to furnish carbon to the produce of two hundred millions of acres of cultivated land.

Whence is all this carbon derived? It is a portion of that which has been conveyed into the stomach in the form of food. Suppose the carbon contained in the daily food of a full-grown man to amount to one pound—which is a large allowance—then it appears that, by the ordinary processes of respiration, at least one third of the carbon of his food is daily returned into the air. In other animals the proportion returned may be different from what it is in man, yet the life of all depends on the emission to a certain extent, of the same gas. And since all are sustained by the produce of the soil, it is obvious, that the process of animal respiration is one of those methods, by which it has been provided, that a large portion of the vegetable productions of the globe, should be almost immediately resolved into the simpler forms of matter, from which it was originally compounded,
and again sent up into the air to minister to the wants of new races.

2. Another important source of carbonic acid is familiar to you in the results of artificial combustion. During this process, the carbon is made to combine with the oxygen of the atmosphere, and the vegetable matter is resolved again into carbonic acid and water. It is impossible to say what proportion of the carbon absorbed during the general vegetation of the globe, is thus annually restored to the atmosphere by the burning of vegetable matter. That it must be very great, will appear from the single fact, that by far the greater part of the globe is dependent for its supply of fuel on the produce of its forests. The coal—which, you are aware, is of vegetable origin—consumed in Great Britain alone is estimated at twenty millions of tons, containing on an average at least 70 per cent., or 14 millions of tons of carbon. But if the annual produce of an acre of cultivated land contain, as we have before estimated, half a ton of carbon derived from the air, the coal consumed in that country would supply carbonic acid to the crops grown on 28 millions of acres. Or, since in Great Britain about 34 millions of acres are in cultivation, the coal they annually consume produces a quantity of carbonic acid which is alone sufficient to supply food to the crops that grow upon \( \frac{3}{10} \) of the arable land of that country.—Johnston.

In connection with this subject, I must draw your attention to one interesting, as well as important, fact. I have spoken of coal as a substance of vegetable origin, and there is no doubt that all the carbon it contains, once floated in the air in the form of carbonic acid. But the period when it was so mixed with the atmosphere, is remote almost beyond conception. When, therefore, we raise coal from its ancient bed and burn it on the earth’s surface, we add to the carbon of the air a portion which has not previously existed in the atmosphere of our time. How interesting it is to contemplate the relations, at once wise and beautiful, by which through the operation of such laws, dead organic matter, intelligent man, and living plants, are all bound together! The dead tree and the fossil coal lie almost useless things in reference to animal and vegetable life—man employs them in a thousand ways as ministers to his wants, his comforts, or his dominion over nature—and in so doing, himself directly, though unconsciously, ministers to the wants of those vegetable races, which seem but to live and grow for his use or sustenance.
3. I shall make but a few remarks on the third head, viz: the production of carbonic acid by the natural decay of vegetable matter, as you will readily perceive that it is in reality a slow combustion. The carbon of a burning body unites directly with oxygen and forms carbonic acid. In the natural process of decay, however, at the ordinary temperature of the atmosphere, vegetable matter is exposed to the action of both air and water; these both co-operate in inducing and carrying on decomposition, and hence carbonic acid is not, as in the case of combustion, the chief or immediate result. In the soil the vegetable matter is continually undergoing decay, various substances are produced in greater or less quantity, some solid, some liquid, and some gaseous—but all of them are only hastening—some by one road, so to speak, and some by another—towards that final destination which sooner or later they are all fated to reach; when, in the form of carbonic acid and water, they shall be in a condition to minister again to the nourishment of all plants. It is upon the final result of this natural decay to which all vegetable matter is subject; that the carbonic acid of the atmosphere depends for its largest supplies. The rapidity with which organized bodies perish, and become resolved into gaseous compounds, depends partly upon the climate and partly on the nature of the substances themselves—but all hurry forward to the same end, and it is with difficulty that we are able for a time to arrest or even retard their steps. It is by this perpetual and active obedience of all dead matter to one fixed law, that the existing condition of things is maintained.

4. There is still another source of carbon, viz: the natural evolution of carbonic acid in volcanic countries. It is exceedingly difficult, if not absolutely impossible, to estimate the quantity of this gas which rises into the air in such circumstances over an extensive tract of country, fractured and broken up by volcanic agency—where the outlets are numerous, and the rate at which the gas escapes very variable. That in many localities it must be very great, however, there can be no question. In a single volcanic district, the annual evolution of carbonic acid from springs and fissures, has been estimated by Bischof at not less than 100,000 tons, containing 27,000 tons of carbon. It is obvious, however, that if the whole of the carbon contained in the produce of the general vegetation of the globe be ultimately restored to the air—either by the respiration of animals, by the natural and slow decay of vegetable matter,
or by the more rapid process of combustion—the constant addition of carbonic acid from volcanoes, and from the combustion of fossil coal, should gradually, though slowly, augment the proportion of this gas in the air we breathe; unless it be perpetually undergoing a permanent diminution, to at least an equal extent, from the operation of other causes. Such compensating causes are doubtless continually active on the surface of the earth. It is well established that the waters of the ocean absorb a notable amount of carbonic acid, which, so far as we know, is not returned, at least in our time, to the atmosphere. The waters which flow into the sea constantly bear down with them portions of animal and vegetable matter, much of which is permanently imbedded in the deposite of clay, silt and sand, which are continually in the course of formation. And lastly, in many parts of the world, much vegetable matter accumulates in the form of peat, becomes buried beneath clay and sand, and thus is prevented from undergoing the natural process of decay. It is impossible to say how much carbon is permanently withdrawn from the atmosphere by these several agencies. There is reason to believe that it is quite as great as the quantity added to the air by the combustion of coal, and by the evolution of carbonic acid in volcanic districts.—Bischof on Heat of the Globe.

The general conclusions, therefore, which we seem justified in drawing in regard to the supply of carbonic acid to the atmosphere are as follow:

1. That a large portion of the carbonic acid absorbed by plants is immediately and directly restored to the air by the respiration of the animals which feed upon vegetable productions.

2. That a still larger portion is more slowly returned by the gradual reconversion of vegetable substances into carbonic acid and water during the process of natural decay.

3. That nearly all the remainder is given back in the results of ordinary combustion.

4. That a further portion, which has not previously existed in the atmosphere of our time, is conveyed to it by the burning of fossil fuel, and by the emission of carbonic acid from cracks and fissures in the surface of the earth; yet that the quantity thus added cannot be supposed to exceed that which is constantly and permanently separated from the atmosphere by other causes. Many have thought it to be somewhat less, and that, consequently, the carbonic acid is slowly diminishing; we have, however, no satisfactory
evidence either from theory or experiment, that it has undergone any appreciable diminution since man has become an occupant of this planet.—Johnston, op. cit. supra.

We have already shown that an immense amount of carbon is converted into carbonic acid during the processes of animal respiration and artificial combustion. Of course this must be accomplished at the expense of the oxygen of the atmosphere. Chemistry informs us, that as carbonic acid consists of 73 per cent. of oxygen, it must require about 266 millions of tons of oxygen, to convert the 100 millions of tons of carbon which men and animals are annually throwing off from their lungs, into carbonic acid. The immense amount withdrawn by combustion is not taken into this calculation. You are, doubtless, ready to ask, whether this enormous abstraction of oxygen does not diminish the amount of this gas in our atmosphere, and thus render the air unfit for the respiration of man and animals?

A little calculation will place this question in the proper light. You will recollect that the weight of the whole atmosphere is equal to 15 lbs. on every square inch of the surface of the earth: the oxygen in it constitutes 21 per cent of its bulk, or about 23 per cent of its weight; hence it follows that the weight of the oxygen is nearly $3\frac{1}{2}$ lbs. on every square inch. The pressure, therefore, upon an acre amounts to 9,801 tons, and upon a square mile 6,272,640. Estimating the superficial extent of our globe at 197½ millions of square miles, it follows that the weight of the whole of the oxygen in the atmosphere is nearly 1,239 billions of tons! Hence it appears, that 4½ millions of years would be required for man and animals, abstracting it at the rate of 266 millions of tons per annum, to exhaust all of the oxygen from the air!! The amount consumed in combustion has not been taken into this calculation; but it is obvious, that, exaggerating all the data, not less than 800,000 years would be required for the animals living on the surface of the earth to consume the oxygen entirely. Consequently, if we suppose that an analysis of the air had been made in 1800, and there were no causes in action to replace the oxygen abstracted from it during the entire century, the animals at the same time all continuing to live, the analyst in 1900 would find the oxygen of the air diminished by $\frac{1}{8000}$-th of its weight; a quantity which is beyond the reach of our most delicate methods of observation, and which, assuredly, would have no influence whatever on the life of animals or plants. In regard to the permanence of the composition of
the air, we may say with confidence, that the proportion of oxygen is secured for many centuries; yet as it is not in-exhaustible, it is interesting to inquire whether Nature has not furnished the means of replacing that which has been abstracted, and thus securing an exact compensation?—You will anticipate me, when I say, that such a compensation has been provided, in the peculiar relations of the functions of vegetables and animals, which retains the atmosphere in a condition of eternal identity of constitution. The growing plants in appropriating the carbonic acid which is emitted by animals, decompose it, and liberate an equal volume of oxygen. It is obvious, therefore, that all of the oxygen consumed by animals, is returned to the atmosphere in the process of eliminating carbon by plants; the 100 millions of tons of carbon annually taken up by vegetables from animals, furnish the air with 266 millions of tons of oxygen—precisely the amount abstracted by animals.

Animals continually produce carbonic acid, water, ammonia—plants incessantly consume ammonia, water, carbonic acid. What one class of beings gives to the air, the other takes back from it; so that to take these facts at the loftiest point of view of terrestrial physics, we must say that, as to their truly organic elements, plants and animals spring from the air—are nothing but condensed air. To enable vegetables to effect the reduction of carbonic acid, water, and ammonia, another agent is brought into action—it is solar Light. Through her influence, the carbonic acid yields its carbon, the water its hydrogen, and the ammonia its nitrogen. These elements unite, organized matters form, and the earth puts on its rich carpet of verdure. It is a circumstance well worthy of interest, that the green leaves of plants absorb the chemical rays of the sun so completely, as to give no image in the Daguerreotype; an extraordinary absorption doubtless, but which explains without difficulty the enormous expense of chemical force necessary for the decomposition of a body so stable as carbonic acid.—Dumas.

The light of the sun, in the existing economy of nature, is indeed equally necessary to the health of plants and of animals. The former become pale and sickly, and refuse to perform their most important chemical functions when excluded from the light. The bloom disappears from the human cheek, the body wastes away, and the spirit sinks, when the unhappy prisoner is debarred from the sight of
the blessed sun. In his system, too, the presence of light is essential to the performance of those chemical functions on which the healthy condition of the fluids depends. The atmosphere appears to us as containing the primary substances of all organization. In aid of it comes light, and develops the vegetable kingdom—innumerable producer of organic matter—plants absorb the chemical force which they derive from the sun to decompose carbonic acid, water and ammonia; as if they realized a reducing apparatus superior to all those with which we are acquainted; for none of these would decompose carbonic acid in the cold. Next come animals, consumers of matter and producers of heat and force, true apparatus for combustion. We are not stopped by the expression cold-blooded animals, which would seem to designate some animals destitute of the property of producing heat. Iron, which burns vividly in oxygen, produces a heat which no one would deny; but reflection and some science is necessary in order to perceive, that iron which rests slowly in the air disengages quite as much, although its temperature does not sensibly vary. No one doubts that lighted phosphorus in burning produces a great quantity of heat. Unkindled phosphorus also burns in the air, and yet the heat which it develops in this state was for a long time disputed. So as to animals, those which are called warm-blooded burn much carbon in a given time, and preserve a sensible excess of heat above surrounding bodies; those which are termed cold-blooded burn much less carbon, and consequently retain so slight an excess of heat, that it becomes difficult to observe it. But nevertheless, reflection shows us that the most constant character of animal existence resides in this combustion of carbon, and in the development of carbonic acid which is the result of it. Whether the question be of superior or inferior animals; whether this carbonic acid be exhaled from the lungs or from the skin, does not signify; it is always the same phenomenon, the same function.

It is in animals undoubtedly that organized matter puts on its highest expression. But it is not without suffering from it that this change is effected. The brute matter, organized by slow degrees in plants, comes, then, to perform its part in animals, and serves as an instrument for sensation and thought; then vanquished by this effort and broken, as it were, it returns brute matter to the great reservoir whence it came. Borrowing from modern sciences an image of sufficient magnitude to bear comparison with
these great phenomena, I should liken the existing vegetation—truly a storehouse in which animal life is fed—to that other storehouse of carbon constituted of the ancient deposits of coal, and which, burnt by the genius of Papin and of Watt, also produces carbonic acid, water, heat, motion—one might almost say life and intelligence. And if we add to this picture, already, from its simplicity and its grandeur, so striking, the indisputable function of the solar light, which alone has the power of putting in motion this immense apparatus, we shall be struck with the import of these words of Lavoisier: "Organization, sensation, spontaneous movement, life, exist only at the surface of the earth, and in places exposed to light. It would seem that the fable of the torch of Prometheus was the expression of a philosophic truth which had not escaped the ancients.—Without light, nature was without life, and was dead and inanimate: by the gift of light, a beneficent God spread upon the surface of the earth organization, feeling and thought." These words are as true as they are beautiful. If feeling and thought, if the noblest faculties of the soul and of the intellect, have need, for their manifestation, of a material covering, to plants is assigned the framing of its web with the elements which they borrow from the air, and under the influence of the light which the sun, its inexhaustible source, pours in unceasing floods upon the surface of the globe. And as if, in these great phenomena, all must be connected with causes which appear the most distant from them, we must moreover remark how the ammonia, the nitric acid, from which plants borrow their nitrogen, are themselves partly derived from the action of the great electric sparks which flash forth in stormy clouds, and which—furrowing the air through a vast extent—produce there the nitrate of ammonia which analysis detects in it. Thus, from the craters of those volcanoes whose convulsions so often agitate the crest of the globe, continually escapes carbonic acid, the principal nutriment of plants; from the atmosphere flashing with lightnings, and from the midst of the tempest itself, there descends upon the earth the other and no less indispensable nutriment of plants, that whence they derive most of their nitrogen, the nitrate of ammonia, contained in the thunder-showers.

To sum up, then, we have seen that plants constitute an immense apparatus for reduction, in which is habitually created true organic matters fit for the assimilation of animals. On the other hand, animals constitute an immense
apparatus for combustion—reproducing the elements, which are returned into the air and the earth. Thus, it is in the vegetable kingdom that the great laboratory of organic life resides; there it is that the vegetable and animal matters are formed, and they are produced at the expense of the air and inorganic constituents of the soil. From plants, these matters pass ready-formed into the herbivorous animals, which destroy a portion of them, and accumulate the remainder in their tissues:—From these, they pass unaltered into the carnivorous animals, who destroy or retain some of them according to their wants. Lastly, during the life of these animals, or after their death, these organic matters, as they are destroyed and resolved into their ultimate elements, return to the atmosphere and to the earth—the reservoirs whence they proceeded—to be again used in perpetuating the mysterious cycle of organic life on the surface of our planet. It is thus, that the grand "Physiological Balance" in organized beings—so eloquently illustrated by M. Dumas—is maintained:—adaptaions, adjustments, reciprocal dependence of parts, and conformity of arrangement, appear everywhere pervading both systems; checks and compensations are perpetually in operation, which must maintain the equilibrium between the kingdoms of organic nature—just as the masses of the planets—the eccentricities of their orbits—the direction of their motions—and the inclinations of the planes in which they revolve, are all arranged so as, according to the beautiful theorems of Lagrange and Laplace, to preserve the stability of the solar system, by affixing limits, maxima and minima, between which the irregularities oscillate.

To my mind, nothing can exceed the beauty of the contrivance, the exquisiteness of the adaptation. Equally kind and bountiful, yet provident, is nature in all her operations, and through all her works. Neither skill nor materials are ever wasted; and yet she ungrudgingly dispenses her favors, apparently without measure—and has subjected dead matter to laws which compel it to minister, and yet with a most ready willingness, to the wants and comforts of every living thing. And how unceasingly does she press this her example not only of unbounded goodness, but of universal charity, on the attention of the man of science. Does the corn spring more freshly when scattered by a Christian hand? Are the harvests more abundant on a Protestant soil? And does not the sun shine alike, and the dew descend, on the domains of each political party? So
science, from her daily converse with nature, fails not sooner or later, to take her hue and color from the perception of this universal love and bounty. Party and sectarian differences dwindle away and disappear from the eyes of him who is daily occupied in the contemplation of the boundless munificence of the great Impartial; he sees himself standing in one common relation to his fellow men, and feels himself to be most completely performing his part in life, when he is able in any way or in any measure to contribute to the general welfare of all. It is in this sense too that science, humbly tracing the footsteps of the Deity in all his works, and from them deducing his intelligence and his universal goodness—it is in this sense, that science is of no sect, and of no party, but is equally the province, and the property, and the friend of all.