EXAMINATION

OF THE

VIEWS ADOPTED BY LIEBIG

ON THE

NUTRITION OF PLANTS.

BY

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ON THE

NUTRITION OF PLANTS.

THE onward career of analysis, from mineral nature to the study of organic bodies, has nearly broken down the barrier between Chemistry and Vegetable Physiology. The publication of Liebig's work "On the Chemistry of Agriculture and Physiology," marks an era of surpassing import in Chemical Science, as well as in the Philosophy of Plants. It is not to any unexpected novelty in its facts or principles that that work owes its excellence. It is because it discloses, in one unbroken view, the growing evidence of the unity of the operations of Nature,—because it sets the mind at ease with itself on many matters difficult of belief—because it affords the testimony of a competent judge, one of the acknowledged masters in the great art of interpreting Nature, to the reality of many unlooked for links between separate provinces in the economy of the natural world—and because it thereby prepares us patiently to contemplate relations, which, at first sight, seem too remote from the ordinary line of our thoughts to come within the compass of the human faculties, and even too daring to obtain our unqualified faith.

But Liebig's work is not a treatise whose object is to resolve points of difficulty in the economy of plants. It is rather an appeal in behalf of the trust-worthiness of certain great principles of investigation, the value of which in guiding the onward progress of physiology has been too little recognised in past times. His views turn on particular methods of inquiry as necessarily leading to the truth ; while it may be feared that his propositions occasionally partake of the character of assumptions made to illustrate the application of his principles, rather than of inferences, in the exactness of which an implicit reliance can be placed.

My object at present is to examine the views adopted by

Liebig on the nutrition of vegetables, for the purpose of determining how far these are just, and with what limitations they require to be received.

The following propositions represent the spirit of the opinions on which I wish to comment.

1*st*, That the food of plants is strictly of a mineral or inorganic nature.

2*d*, That ammonia, carbonic acid, and water impregnated with a few saline matters, are the sole aliments of plants.

3*d*, That the organic matter of soils must pass into the mineral state, namely, into water with a saline impregnation, carbonic acid and ammonia, before it can become subservient to the uses of vegetation.

4*th*, That the saline matters and the like, which form the ashes of plants, are, without exception, taken up from the soil, and are, in no respect, the product of vegetation, as was taught in the beginning of the present century.

Thus the maxims adopted by Liebig on the nutrition of plants are of a negative character; for, if it can be shewn that the doctrine of the nutrition of plants by organic compounds in the soil is unfounded, then the truth of Liebig's grand axiom, as to the mineral nature of the food of plants, is established at once.

There are two groups of opinions to which those of Liebig stand in a negative relation, namely, those which represent the food of plants as solely or principally of an organic kind, and those again which admit the food to be inorganic in the main, yet available for nutrition only when certain azotised matters of an organic nature, derived from the soil, are present.

It is the first of these two groups of opinions only, that stands opposed in particular to what Liebig inculcates, and to this I propose to address myself chiefly; for, unless all opinions of this stamp be overthrown, it is impossible to subscribe to his doctrine.

If the food of plants be solely organic substance, then there must have been originally (or at least at one time*) in

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* To assume that soil was formed from the atmosphere in the course of time, by the gradual rise of the vegetable kingdom, would be to beg the

the soil a store of organic matter adequate to the development of the substance of all plants and animals, as well as to the repair of the annual waste in both organic kingdoms, from their rise down to the period of their final extinction. By the annual waste of organic substance, in both kingdoms, is to be understood the amount which passes into the mineral or inorganic state, without having acted as nourishment to plants.

The animal kingdom is dependent exclusively on the organic matter of the vegetable kingdom for its support. Hence, it follows, that, by the hypothesis opposed to Liebig's, both organized kingdoms must be maintained at the expense of the organic matter of the soil. There are only two conditions under which this is possible; either that there is no material waste of organic matter in nature; or, what is the same thing, no conversion of it to any great extent into mineral substance, but, on the contrary, a continual circulation of organic matter, ever changing, but still preserving its organic character, from the soil to the fabric of plants, and from plants to animals, and so back, without actual loss of organic form, to the soil; or if there be necessarily much waste, that, after the original production of the two organised kingdoms to much the same extent to which they now exist, there was left in the soil a quantity of organic matter adequate to supply the annual waste from the beginning of the present system of things downwards, and in all time to come, till the extinction of the existing races of organised beings and living organisms.

But the waste of organic matter is undeniably very great over the surface of the earth. It would require a separate dissertation to explain all the various modes in which organic matter is unceasingly reduced to the mineral state.

In the single function of respiration, each mammal con-

question, the merits of which are under consideration. The question, then, as to the formation of soil must, like the origin of organic species, be regarded as belonging not to the laws of nature, but to the origins of things, and, therefore, forbidden in inductive science. What in this inquiry is called the beginning of the present system of things, must, consequently, be considered as a state not essentially differing from that of the earth's surface at present.

sumes annually much more than its own weight of carbon, which is but one of the constituents of organic matter. Birds consume more, the less perfect animals consume less. Hence it cannot be an over-estimate to assume, that, on an average, every living creature annually destroys in respiration alone, its own weight of the carbon of organic compounds. In insects, the consumption of oxygen, which is a near measure of the carbonic acid thrown out in respiration, is as great compared with their weight as in mammals ; and the quantity destroyed by mammals, in proportion to their weight, is nearly the mean between the greater amount consumed by birds, and the less amount required for the respiration of cold-blooded animals in general. The objection of Berzelius, that the carbon consumed in respiration is overrated, because it is more than equal to the whole carbon in the average amount of food, plainly involves an over-estimate of the average proportion of water, and an under-estimate of the average proportion of carbon, in the diet of men ; he makes the water three-fourths of the weight, and the carbon one-half of the remainder, which is true of only a few articles of food.

A second great source of the conversion of organic matter into carbonic acid is the burning of wood in fires, of lamp-oil, of tallow and wax in candles, of cotton and rushes for wicks, and of other such vegetable and animal substances in domestic life. Thus the means of keeping himself warm, of cooking his victuals, and of supplying himself with light in the absence of the sun,—conveniences not voluntarily dispensed with by any individual of the millions of the human race—involve a daily consumption of much organic matter all over the globe, except in the few localities in which a supply of heat and light, in the shape of coal, is afforded from the organic remains of a former world. Of the quantity of wood destroyed in common fires, one may judge from the fact, that Great Britain, containing less than a fiftieth part of mankind, at a moderate calculation, consumes annually, besides peat and wood, 20,000,000 of tons of coal, 17,000,000 of which are reckoned to be for mere domestic use. Accidental conflagrations, and the too frequent ravages of war, in houses, ships, forests, and the like, swell the amount of waste by fire. A candle which lasts for an evening, destroys between 1 and 2 ounces of carbon. Hence, in the 250,000,000 of families which make up the great family of the human race, the nightly consumption of tallow, oil, or the like, must amount to many millions of pounds.

Some crops are raised to be burned; so that the whole, or nearly the whole, annual produce would be so much loss to the organic matter of the general soil. Of this kind are tobacco, kelp, and barilla.

In the process of fermentation, by which wine, beer, spirits, and vinegar, are produced, a large quantity of organic matter is reduced to the mineral state, and that without denying the name of organic compounds to the wine, beer, alcohol, and vinegar, formed in the mean time. How enormous, then, must have been the total loss of organic matter in this way since the time when the secret of converting the juice of the grape into wine was first discovered. To the waste caused in this way should be added that which takes place daily by the formation of carbonic acid, in making fermented bread.

But the loss by these last sources of destruction are as nothing compared with that which takes place everywhere, but particularly in cities, by the complete decomposition of numerous animal and vegetable substances, the refuse of both organic kingdoms, when that refuse fails to be collected and applied to its proper use, as manure to the soil. How little of the organic matter conveyed from every great town to the adjacent sea or river escapes complete decomposition! The product of all our fisheries can make but a small reduction on the amount of this loss. How much of such organic matter is carried away annually from the soil itself by rivers, to become incorporated with the deposits that are ever forming at their confluence with the sea.

All the numerous articles of furniture, clothes, and equipment in general use, composed of linen, woollen, cotton, straw, leather, furs, hair, horn, bone, and ivory, by the hypothesis denied by Liebig, draw their origin exclusively from the organic matter of the soil; and whatever part of these undergoes complete decomposition, or fails to return to the soil without the loss of its organic character, would be so much withdrawn from the original stock of organic matter, provided against the demands of the two living kingdoms of nature during their continuance. Many such substances are designedly destroyed, to a great extent, to furnish compounds of cyanogen and ammonia. Other sources of this kind of destruction will readily suggest themselves to every one. I will, therefore, content myself with adding one more, namely, the hourly destruction in the article of paper; how little of the miles of paper daily manufactured in the United Kingdom returns to the soil undecomposed!

Thus, on the hypothesis of organic matter being the sole food of plants, there must have been from these and other sources of transformation an enormous annual diminution of the quantity of organic substances in the soil ever since the commencement of the present system of things; and it follows irresistibly that the two living kingdoms of nature could endure no longer than while the primitive store should withstand this annual demand upon it. Hence, if the truth of this hypothesis could be established, we should have a principle, the application of which, as soon as some precision can be imparted to the data, would bring out the exact period after which the present system of organic nature must cease to exist. On the contrary, if Liebig's idea of the food of plants being exclusively mineral, can be realised, it follows, that, whatever destructive accidents the two kingdoms may be liable to in the course of time, they have, in their own economy, ample provision for an unlimited duration.*

* Since the above communication was read, the translation of Müller's Chemistry of Vegetable and Animal Physiology, from the original Dutch, by Dr Fromberg, has appeared. In this work Müller predicts the extinction of the animal kingdom after a term of years, owing to the poisonous effect of carbonic acid accumulated faster in the air by an increase of animal respiration than it is decomposed by plants. He forgets here, that men and other animals cannot increase faster than the means of sustenance are supplied by the vegetable kingdom, and that, according to his own views, this vegetable sustenance cannot augment without a corresponding removal of carbonic acid from the atmosphere. The abundance of the crops raised for food must compensate for their small bulk, as compared with the pristine forests of the earth's surface; and,

Our next step is to examine what kinds of data exist for a calculation of the present amount of organic matter, or, for greater simplicity, of the present amount of carbon, in the organic compounds of the soil of the earth, to set against the annual demands supposed to be made upon it. The most devoted partisan of the theory of the organic nature of the food of plants must regard, I think, the following admission as even extravagantly favourable to his opinion. Notwithstanding the immense tracts of our planet covered by the ocean, inland seas, lakes, rivers, sandy deserts, rocks, rocky mountains, and the eternal snows of Alpine and the Polar regions, I assume one-fifth of its surface to be covered with soil to the depth of one foot; one-tenth, or ten per cent. of this soil to be organic matter, and three-fifths of this organic matter to be carbon. On these data, taken in round numbers, I find there would be nearly three billions and a half of tons of carbon in the organic compounds of the soil of such a portion of the earth's surface.

This limit the quantity of soil cannot possibly exceed; and it would probably bring us nearer the truth to make the estimate of its amount on such data as the tenth part of the earth's surface, six inches of depth and one-twentieth, or five per cent. of organic matter. If these last data be assumed, the first quantity, namely, three billions and a half of tons of carbon, will become reduced to one-eighth, or to something more than four hundred thousand millions of tons.

Between these two limits the truth, I think, must lie.

If the first estimate be adopted, the soil would bear an annual drain of 600 millions of tons of carbon for nearly six thousand years, or for a period equal to that which seems to have elapsed since man appeared upon the earth. On the second estimate, the soil, at the same rate of consumption, would be completely exhausted of carbon, and, therefore, of organic matter, at the end of 740 years.

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according to the probable data assumed in the paper, the conversion of the whole carbon of the organic matter of the soil, and of living plants and animals into carbonic acid, would not more than double the small proportion of that gas existing at present in the atmosphere.

But, it will be asked, does the annual expenditure of the carbon of organic compounds rise at present so high as 600 millions of tons?

If the daily waste of carbon by the human race, in the act of respiration alone, be estimated at no more than five ounces for each individual, the annual consumption will amount to one-twelfth part of the above quantity, or to 50 millions of tons.

Domesticated animals, horses, and other beasts of burden, dogs, oxen, sheep, hogs, and poultry, as coming to an early maturity, consume at least twice this quantity, or 100 millions of tons.

The rest of the animal creation cannot dispense with less than the sum of these two quantities, or 150 millions of tons.

And the other numerous sources of waste above mentioned, including combustion, cannot be over-rated at as much again, or 300 millions of tons—or, in all, 600 millions of tons. All the above estimates are designedly under-rated.*

No doubt the final extinction of the two living kingdoms of nature would be somewhat protracted beyond the period assigned under either of the above suppositions, because a gradual diminution in the sources of expenditure could not but at last commence, while under the diminution of plants and animals successive additions would be made to the soil. But it seems probable that an exact calculation would shew that all the carbon of living plants and living animals would not supply the present rate of expenditure much above 300 years; while, on the other hand, there is good reason to believe that the rate of expenditure is still rapidly increasing, and that it must hereafter greatly exceed its present limits before any decline is possible.

The exhaustion of the fertility of land by successive grain crops gives some countenance to the belief of organic matter in the soil being the chief food of plants; but this is susceptible of a different explanation, while other facts lead to the contrary inference; for instance, the manifest increase in quantity of organic matter in the soil of a field after some

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* See Appendix.

years of permanent pasture. Nor does the aspect of the earth's surface at present give any sensible indications of its having already lost half of the original store of material destined for the maintenance of plants and animals.

But to enter at present on the changes of particular parts of the soil would lead me too much into matters of detail, while the general argument with which I am engaged is but half concluded.

Hitherto I have supposed the hypothesis to assume (what some physiologists still maintain) that there is no decomposition of the carbonic acid of the air by the green parts of vegetables, or, at least, that there is no compensation by the vegetable kingdom for the carbon of organic compounds destroyed by the animal kingdom, and other sources of waste in nature. But this is not the form in which the hypothesis is most generally maintained at present—the evidence of the appropriation of carbon by plants from the inorganic carbonic acid of the atmosphere is so conclusive, that the opposition to this belief may be regarded as already making its expiring effort. And here it should be remarked, that the acknowledgement of a great part of the constituent carbon of plants being drawn from an inorganic compound in the atmosphere, is a plain admission of an analogy which goes far to make it probable that all the food of plants is inorganic.

But does this limitation better the hypothesis of the food which the soil affords being organic matter. Carbon is not the only constituent of plants: wherever the vegetable tissue contains carbon, it contains hydrogen also, in fixed proportions, along with oxygen, and even nitrogen. Now, it cannot avail to assume that the exhaustion of the carbon of the soil is postponed by a large proportion of the carbon of plants being derived from inorganic matter in the atmosphere, while the remaining portion, along with their hydrogen, &c., is drawn from organic matter in the soil. For the fixed constitution of the vegetable tissues must be preserved as respects all their component elements. A plant cannot fix carbon in its substance without obtaining from some source the due relative proportion of hydrogen and its other elements. If this hydrogen be supposed to be obtained from the organic matter of the soil, all the advantage of the supply of carbon from the atmosphere is lost; for the organic matter of the soil, in supplying the due proportion of hydrogen, must set free as much carbon as would have sufficed for the growth of the plant, were none afforded by the atmosphere—unless, indeed, the organic compounds of the soil contained a less proportion of carbon, as compared with their hydrogen, than the tissues of plants; which is known to be contrary to the truth. Thus, were the organic matter of the soil the sole source of the hydrogen of plants, there would be a continual accumulation of carbon in the soil, unless it be supposed to be as constantly added to the atmosphere, by combining with the oxygen absorbed into its porous substance.

It is manifest, however, particularly on this last supposition, that the soil would be exhausted as rapidly as if no carbon were afforded to plants by the atmosphere.

On the contrary, the assumption adopted by Liebig—of water being at once the source of the constituent hydrogen and oxygen of plants—points to an inexhaustible supply of these two elements, such as can keep pace with the fixation of carbon from the air, however rapid that may be.

One difficulty presents itself, namely, that some vegetable compounds contain a considerably larger proportion of hydrogen, as compared to their oxygen, than water. And this fact seems to point to the conclusion, that there are other sources of the hydrogen of plants; and these may be inorganic, as ammonia and light carburetted hydrogen. This subject I must relinquish for the present; but I would remark, that, in connexion with the supposition of ammonia being a source of the hydrogen of the vegetable kingdom, the evolution of nitrogen from the leaves of plants has not yet obtained a sufficiently attentive examination.

Liebig assumes that the source of the oxygen of plants is the decomposition of water. And few difficulties present themselves on this head not already adverted to. The quantity of oxygen, however, absorbed by the soil in the preparation of the ground for seed, and during the growth of plants, is plainly greater than might be expected from the small proportion of carbon derived from the soil. This point, also, deserves farther examination.

The source of the nitrogen of plants is, according to Liebig, exclusively from ammonia accumulated in the soil. He refuses to believe that the nitrogen of the air enters into the constitution of plants, either directly, in its simple state, or indirectly, by passing first into ammonia. This is a topic of the very last importance, and is the principal novelty in Liebig's view of the nutrition of vegetable bodies.

The ammonia that serves for food to plants is, according to Liebig, originally of mineral origin ; for example, from volcanic sources. This ammonia passes into the azotised parts of plants, especially into those destined to be the food of animals ; and this is the source of the abundant nitrogen of the animal kingdom. The excretions of animals, and the decomposition of animal and vegetable substances, restore this ammonia to the soil, or, if it has escaped into the air, it is brought back by rains ; in either case to pass through the same circuit.

This view of Liebig's will hardly stand the same kind of test to which the idea of organic matter being the sole food of plants was subjected above. For, if his opinion be correct, the amount of organic life on our globe must be limited by the quantity of ammonia existing at the surface ; it never can pass the limit fixed by the quantity of ammonia.

If, then, there be any waste of ammonia, if there be any portion of the nitrogen of plants or animals (both equally by hypothesis derived from this source) which does not return to the state of ammonia, there must be a gradual extinction of the organic world, like what was before referred to in the case of carbon. The only alternative is, that the volcanic, or other similar sources of ammonia, shall be shewn to be in constant operation, so as to compensate for the whole waste here supposed.

But it is impossible that there should not be in nature a great annual waste of ammonia,—that is, a great annual decomposition of it into its mineral elements, or into that form under which, according to Liebig, its nitrogen cannot directly or indirectly avail for the nutrition of plants ; nor does it clearly appear that the sources of its extrication from the bowels of the earth are in uninterrupted operation.

It has been well remarked by Professor Johnson, that the ammonia which rises into the air can hardly escape frequent resolution into its elements, since electric shocks decompose it with ease in the laboratory. In this way it would, according to Liebig, be irrecoverably lost to organic nature.

To this source of waste, I would add, that the ammonia which rises from the decomposition of animal substances at the earth's surface, must, by the law of the diffusion of gases, especially during the long absence of rains, extend itself upwards beyond the limits of aqueous vapour, and will, therefore, set at nought the power of rain to bring it back to the earth's surface. In short, unless the electricity of the higher atmosphere can decompose ammonia, it must go on, slowly accumulating above the point to which aqueous vapour reaches, descending only when the supply from the earth to the lower atmosphere is less copious; and if ammonia be decomposed in the higher atmosphere, we obtain one source of inflammable gas, namely, hydrogen, to feed luminous meteors in that region, the same electric power being capable of causing its union with oxygen into water.* It is to be remarked, however, that, if this decomposition went on for ages evolving nitrogen, there would be an increase in the proportion of atmospheric nitrogen, unless it were again converted into ammonia at the surface.

It would be easy to point out other sources of the waste of ammonia. For example, nitre is formed chiefly (according to Liebig exclusively, as I should infer) at the expense of the nitrogen of animal matter, and it does not appear that

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* Under the ordinary atmospheric pressure at the earth's surface, ammoniacal gas requires, for its liquefaction, a cold equal to -61° of Fahrenheit. This is inferior to the calculated temperature of the planetary spaces, which, according to Fourier, cannot be below -57° F. But, as the cold required for the liquefaction of a gas must increase with its rarefaction, there is no room for the belief that ammonia can separate from the higher atmosphere by passing into the liquid state, and thereby descending into the region of watery vapour.

it returns again to the state of ammonia. In regard to one great source, at least, of the consumption of nitre, namely, the discharge of gunpowder, it is known that the nitrogen is evolved in the uncombined state ; and is thus, under Liebig's view, irrecoverably lost as a means of sustenance to living bodies. Thus, gunpowder would shew itself under a doubly fatal character;—fatal in its immediate effect on life, and fatal, by tending to abridge the duration of the organic world !

But the number of cases now known in which ammonia forms from its elements, makes it impossible to join with Liebig in opinion, that ammonia is not produced from its elements in nature, independently of the presence of organic matter.

This is an interesting subject, but the time already occupied with these observations requires me to be brief.

It is long since the production of ammonia from its elements began to engage the attention of chemists. Priestley observed the formation of the volatile alkali under some circumstances ; and it is not far from sixty years since Austin presented his paper to the Royal Society of London on the formation of volatile alkali. The evidence known to him was sufficient to warrant the conclusion, not merely that nitrogen and hydrogen unite to form ammonia when in the nascent state, but when one only of its elements, namely, hydrogen, is in that state. He refers to the remarkable experiment in which moistened iron filings, in a jar of nitrogen, confined over mercury, produce ammonia ; and concludes that, " when iron rusts in contact with water in the open air, or in the earth, volatile alkali is formed." I am aware that Liebig ascribes the presence of ammonia in rust of iron to absorption from the atmosphere, and that an experiment made in his laboratory is thought to confirm this inference. But on such a point, common evidence is not to be listened to. When a current of moist air is passed over red-hot charcoal, carbonic acid and ammonia are produced. Mülder has recently added other experiments bearing on the same conclusion. Professor Johnson has put this subject in a clear light, and has succeeded, I think, in shewing the strongest reason for believing, that plants, especially in warm climates, derive part, at least, of their nitrogen from the nitric acid of nitrates existing in the soil.

As respects, then, the supply of nitrogen to plants, it is impossible to agree with Liebig farther than that ammonia is part of the food of plants. For a completely definite opinion the time has not yet arrived; but the interest given to this so long neglected subject by Liebig's affirmations, cannot but ensure its complete elucidation within a short period. This part of the subject I conclude with two propositions, which deserve the strictest examination.

1*st,* That ammonia is produced in the soil during the decomposition of parts of plants containing no nitrogen,—the nitrogen being, according to Berzelius, derived from the air; and, 2*d,* in a decomposing mass of animal matter, that the nitrates first formed from the nitrogen of the animal matter, contrary to the common belief of chemists, induce, catalytically, the production of nitrates from the nitrogen of the air.

The last axiom drawn from Liebig's work, on which I proposed to comment, is, that the saline matters contained in plants are drawn exclusively from the soil, and are in no respect the product of vegetation. On this subject I must be more brief than I intended.

The ashes of plants, though not absolutely constant, are nevertheless in so far constant, as to shew that a certain saline constitution belongs, in its most normal and healthy state, to every species. Two difficulties present themselves in the investigation of this subject, namely, the substitution, by a kind of isomorphism, of one substance for another under peculiar circumstances; and the presence, on most occasions, of saline matters which are not essential but accidental. The general principle, as respects the saline constitution of plants taught by Liebig, is sufficiently made out, but the subject has been as yet too little studied in its details. The subject is, indeed, clear enough to a certain extent; but, until the whole of the respective offices of the inorganic and organic portions of the soil be made apparent, some doubts must hang over our conclusions.

Forms of potass and phosphates of a few bases, the most prevalent kinds of saline matter in the vegetable kingdom, exist in small proportion, diffused through the rocks of the crust of the earth. These can get into the soil only by the slow crumbling down of the rocky fragments which contain them. A quick succession of crops, requiring a large proportion of such saline constituents, will so far exhaust a soil of the parts already sufficiently comminuted to afford them; and thus the next crop will be inferior to the former. In process of time, the comminution proceeds; and then the previous fertility, in as far as it is dependent on this cause, returns, or it is restored at once by the same saline constituents being contained in the manure applied.

One thing, at least, is already certain, that the phosphates, which exist so abundantly in the animal kingdom, have no other source but the rocks of the crust of the earth. By the crumbling of these rocks they pass into the soil, from the soil into plants, and from plants, in the composition of vegetable food, into animals, from the excretions of which they pass again into the soil. The general admission of this last proposition is of very recent date, and has cost a great struggle. The contrary was taught by Schrader and Branconnot at the beginning of this century, and their views seem to have taken possession of the minds of naturalists, notwithstanding the opposition of the more philosophic De Saussure.

It is forty years since De Saussure exclaimed, "analysis demonstrates, that all the prevailing substances in the ashes of plants are contained in the soil; and that its soluble part, which alone penetrates into the vegetable economy, contains these substances in greater proportion than the insoluble part." Again, he says, "the explanations which I can give on this point are sometimes far from being perfectly satisfactory. These often require a knowledge which I have not attained—that of the vegetable organism. But they are less absurd than those which ascribe to plants a creative power as respects their elements."*

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* Recherches Chimiques sur la Végétation par Théod. De Saussure. A Paris, 1804, p. 284.

But I must draw this long paper to a conclusion. The spirit in which De Saussure so long since studied the vegetable economy, appears to have become dormant among botanists for a good many years. They had too little faith in the conclusions of modern chemistry to trust to it as an instrument of research. Nor was it surprising, at the commencement of this century, when chemistry was hardly beyond its infancy.

Not a few sciences have suffered severely from the rash transfer to them of principles and modes of investigation, of established success in other kinds of knowledge; but no science which has to do with matter is entitled to reject the conclusions of chemistry, as to the transmutations of which matter is susceptible. Modern chemistry, in so far as facts are concerned, can undergo no considerable change beyond the attainment of greater exactness. And this is true, even though the whole face of the science and its entire nomenclature should completely alter, as, in the course of time, is very likely to happen. But such an alteration is not a denial of its present facts, or a sinking of its past progress, but merely a change of the aspect under which its conclusions are regarded. Hence, whatever knowledge physiology borrows from chemistry, is not lost by the changes to which that science is subject; but must remain available in the study of the vegetable economy, though in an altered form.

Chemistry, in short, must always be the very groundwork of vegetable physiology. It must teach the number, the properties, the relations of the elements, which the vital force combines and operates on. And had this truth been more clearly seen, and more firmly held to, at an earlier period, it would not have been left for Liebig at this late day to surprise the world with the announcement of the great bonds of union which so strictly unite the operations of the vegetable economy with those of mineral and of animated nature. For Liebig has not taught much, the rudiments of which are not to be found in De Saussure's work. De Saussure taught in 1804 that plants fix carbon both from the carbonic acid of the soil and of the atmosphere; that they fix oxygen and hydrogen from water; that they derive their saline matter from the soil. He knew that ammonia is contained in some decomposing vegetable substances; but he does not appear to have arrived at Liebig's conclusion, that it is an essential part of the food of plants; and without affirming what Liebig so pointedly denies, namely, that the extractive matters of the soil are part of the food of plants, he contents himself with saying that these "contribute in a certain proportion to the fertility of the soil;" while he adds, in the same sentence, that "the ashes of these extractive matters contain the same principles as the ashes of plants."* Moreover, De Saussure notices, in particular, that vegetable mould contains more ammonia than the wood from which it forms; and this difference he ascribes to the effect produced on the soil by the numerous insects frequenting it.

It may be seen, then, that the spirit of the view adopted by Liebig is not of recent date. That plants convert mineral substances into their own substance is a proposition almost coeval with our knowledge of the ultimate composition of air, water, and soil. And all that is essential of this proposition remains unchallenged, even if the progress of inquiry shall graft the views of Mülder on those of Liebig, namely, that certain azotised substances formed in the soil, which have not yet lost their organic character, are indispensable. For if such compounds do aid in the nutrition of plants, it manifestly cannot be otherwise, than as yeasts contribute to fermentation. The substance of vegetables is from mineral nature. Plants metamorphose parts of the mineral covering of our planet into organic substance. Animals dissolve the spell bound on it by vegetable life, and re-convert this organic matter into its original mineral condition. Thus, from air, water, and a little soil, all organic bodies are made.

> Sic modo quæ fuerat rudis et sine imagine tellus
> Induit ignotas hominum conversa figuras.

And thus modern science realizes the happy conjecture of the ancients as to the number of the elements. The four elements of the ancients are the elements of organic nature

* Recherches Chemiques sur la Végétation, par Théod. De Saussure, p. 185.

—Air, Water, Earth, and Fire, are in truth the elements of the organic world; for their fire represents that warmth, the absence of which extinguishes all organic life.

A brief notice of the mode in which the numerical results made use of have been brought out may be satisfactory, and will shew that no exaggeration has been practised to the prejudice of the opinion that the food of plants is organic substance.

The area of the earth's surface is roundly estimated in square miles, by multiplying the circumference into the diameter.

24,000 × 8000 = 192,000,000, area of the earth in square miles.

$\frac{192,000,000}{5}$ = 38,400,000, { one-fifth part of the earth's surface in square miles.

The number of square feet in a square mile is 27,878,400; whence 38,400,000 × 27,878,400 = 1,060,520,560,000,000, the number of cubic feet of soil, a foot deep, in the surface of one-fifth part of the area of the earth.

A cubic foot of water weighs 1000 ounces avoirdupois; call soil twice the density of water, which is near its density; then a cubic foot of soil weighs 2000 ounces, or 125 pounds:

125 × 1,060,520,560,000,000 = 132,564,071,000,000,000,

which number represents the quantity of soil in avoirdupois pounds contained in one-fifth part of the earth's surface.

The same reduced to tons is 59,180,388,839,285.

Take ten per cent. of this quantity as organic matter,

5,918,038,883,928.

Take three-fifths of the organic matter as carbon,

3,550,823,320,352; or there is something more than three billions and a half of carbon in the soil of one-fifth part of the earth's surface.

If a thousand millions of men consume daily five ounces of carbon each in respiration, they consume in a year 50,922,420 tons of carbon. A horse, according to Boussingault, throws off, in carbonic acid, 6·07 pounds of carbon, or nearly a ton in a year (·988 ton).

The horses of Great Britain, on a moderate calculation, are estimated at a million and a half;* and the inhabitants of Great Britain are less than a fiftieth part of the human race: say, then, there are fifty times as many horses in the world as in Great Britain, and horses alone will be found to consume every year nearly 75,000,000 of tons of the carbon of organic matter.

An ox or cow converts nearly four and a half pounds of carbon daily into carbonic acid. There are about three millions and a quarter of cattle in Great Britain;† or the cattle of Great Britain must consume

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* Macculloch's Statistical Account of the British Empire, vol. i. page 284.

† Ib. page 490.

more than three millions and a quarter of tons of carbon annually in respiration; and if the black cattle all over the earth be in the like proportion to the number of inhabitants, these alone will consume more than 150 millions of tons of the carbon of organic matter in a year (162,500,000).

The number of sheep in Great Britain is estimated at about 40 millions (39,648,000).* Take the average weight of each at no more than fifty pounds, the weight of the whole comes to nearly a million of tons; or, at all events, since in warm-blooded animals the quantity of carbon thrown off by respiration in a year considerably exceeds the weight of the animals, there must be at least a million of tons of the carbon of organic matter converted yearly into carbonic acid by the sheep of Great Britain.

This should give, for the annual consumption by sheep, over the whole earth, fifty millions of tons of carbon.

Hogs, rabbits, poultry, &c., in Great Britain can hardly amount to less than half the weight of the sheep, or to half a million of tons. It may be reckoned, then, that such animals over the whole earth consume annually not less than twenty-five millions of tons of carbon—thus:

Carbon consumed yearly by men, .	50,000,000 tons.
... ... by horses, .	75,000,000
... ... by cattle, .	150,000,000
... ... by sheep, .	50,000,000
... ... by hogs, poultry, &c.	25,000,000
Combustion of wood, being at half the rate at which coal is consumed for domestic purposes in Great Britain, . .	425,000,000
	775,000,000 tons.

By a reference to the paper it will be seen that many sources of the consumption of the carbon of organic compounds are not taken into account in the above computation; and, in particular, that the consumption by animals in the wild state is not added. It seems not unlikely, then, that instead of 600 millions of tons, at which the annual waste was stated in the text, double that quantity would come nearer the truth.

* Macculloch's Stat. Account of the British Empire, vol. i., p. 496.