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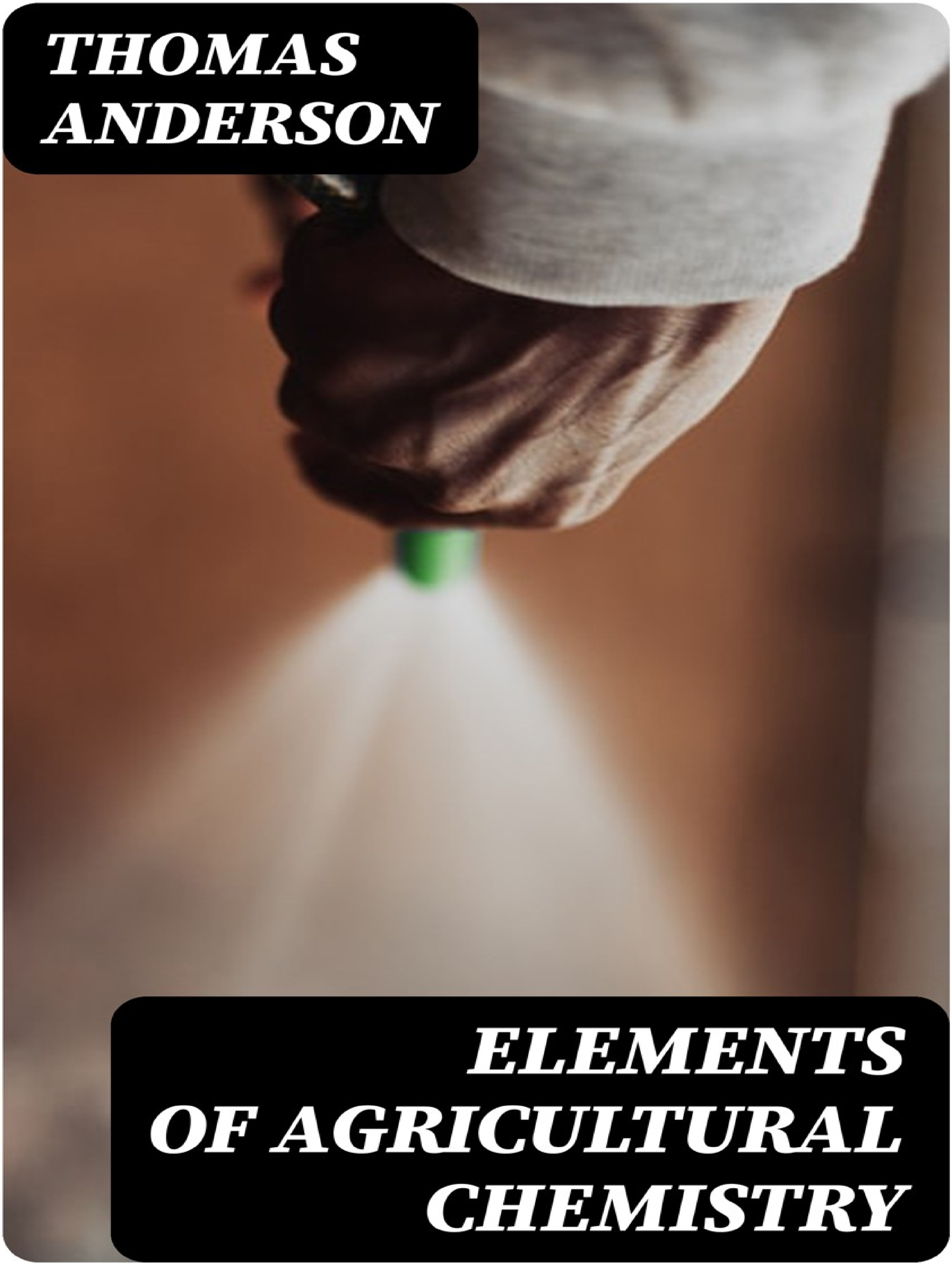
ANDERSON



ELEMENTS OF AGRICULTURAL CHEMISTRY

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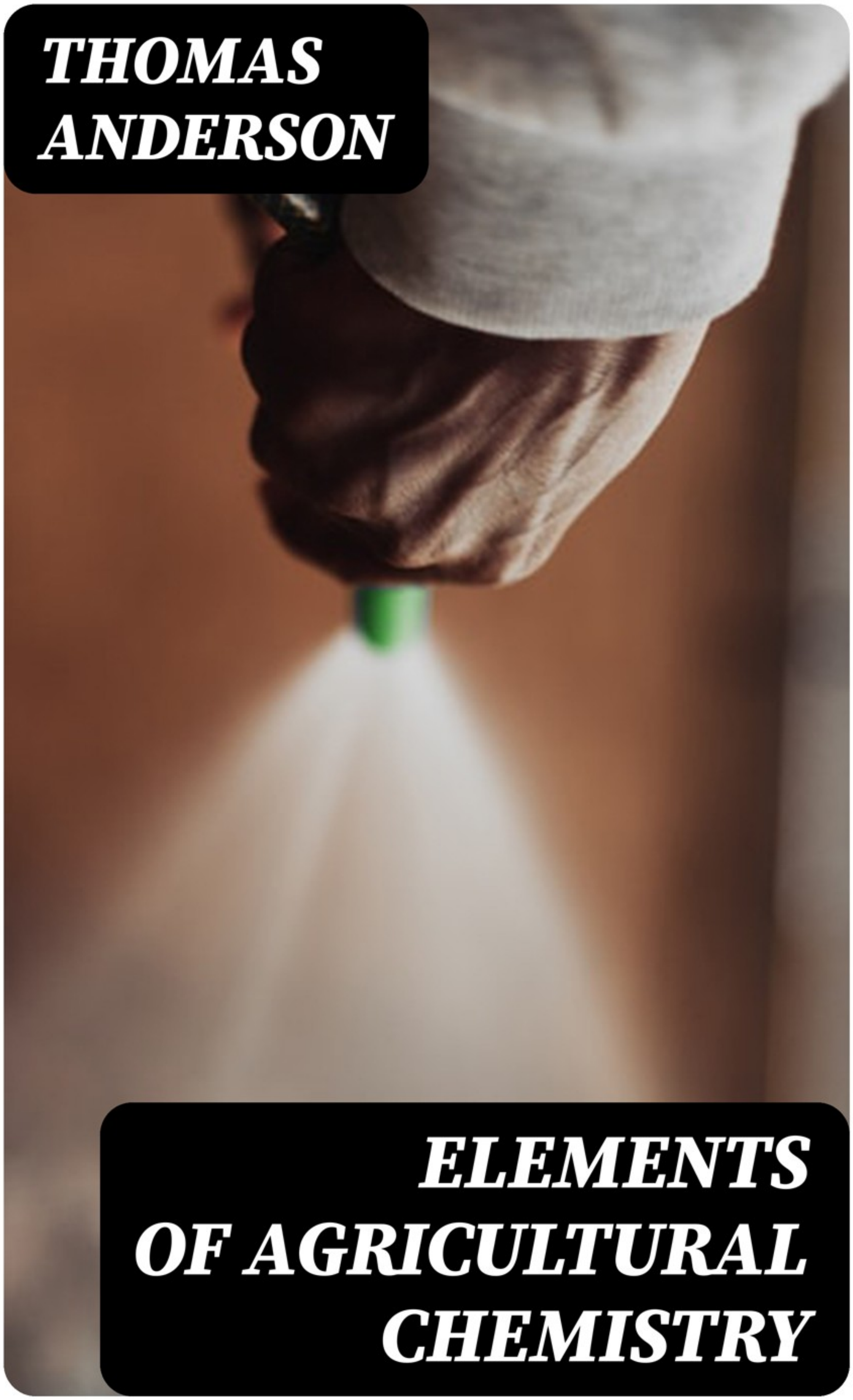

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Thomas Anderson

Elements of Agricultural Chemistry

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PREFACE.

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The object of the present work is to offer to the farmer a concise outline of the general principles of Agricultural Chemistry. It has no pretensions to be considered a complete treatise on the subject. On the contrary, its aim is strictly elementary, and with this view I have endeavoured, as far as possible, to avoid unnecessary technicalities so as to make it intelligible to those who are unacquainted with the details of chemical science, although I have not hesitated to discuss such points as appeared essential to the proper understanding of any particular subject.

The rapid progress of agricultural chemistry, and the numerous researches prosecuted under the auspices of agricultural societies and private experimenters in this and other countries, render it by no means an easy task to make a proper selection from the mass of facts which is being daily accumulated. In doing this, however, I have been guided by a pretty intimate knowledge of the wants of the farmer, which has induced me to enlarge on those departments of the subject which bear more immediately on the every-day practice of agriculture; and for this reason the composition and properties of soils, the nature of manures, and the principles by which their application ought to be governed, have been somewhat minutely treated.

In all cases numerical details have been given as fully as is consistent with the limits of the work; and it may be right to state that a considerable number of the analyses contained in it have been made in my own laboratory, and that even when I have preferred to quote the results of other chemists, they have not unfrequently been confirmed by my own experiments.

University of Glasgow,
1st November 1860.

AGRICULTURAL CHEMISTRY.

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INTRODUCTION.

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That the phenomena of vegetation are dependent on certain chemical changes occurring in the plant, by which the various elements of its food are elaborated and converted into vegetable matter, was very early recognised by chemists; and long before the correct principles of that science were established, Van Helmont maintained that plants derived their nourishment from water, while Sir Kenelm Digby, Hook, Bradley, and others, attributed an equally exclusive influence to air, and enlarged on the practical importance of the conclusions to be deduced from their views. These opinions, which were little better than hypotheses, and founded on very imperfect chemical data, are mentioned by Jethro Tull, the father of modern agriculture, only to deny their accuracy; and he contended that the plants absorb and digest the finer particles of the earth, and attributed the success of the particular system of husbandry he advocated to the comminution of the soil, by which a larger number of its particles are rendered sufficiently small to permit their ready absorption by the roots. Popular opinion at that time was in favour of the mechanical rather than the chemical explanation of agricultural facts, and Tull's work had the effect of confirming this opinion, and turning attention away from the application of chemistry to agriculture. Indeed, no good results could have followed its study at that time, for chemistry, especially in those departments bearing more immediately on agriculture, was much too imperfect, and it was only towards the close of the last century, when Lavoisier established its true principles, that it became possible to pursue it with any prospect of success.

Very soon after Lavoisier's system was made known, Lord Dundonald published his "Treatise on the Intimate Connexion between Chemistry and Agriculture," in which the important bearings of the recent chemical discoveries on the practice of agriculture were brought prominently under the notice of the farmer, and almost at the same time De Saussure commenced those remarkable researches, which extended over a long series of years, and laid the foundation of almost all our accurate knowledge of the chemistry of vegetation. Saussure traced with singular care and accuracy the whole phenomena of the life of plants, and indicated the mode in which the facts he established might be taken advantage of in improving the cultivation of the soil. But neither his researches, nor Lord Dundonald's more direct appeal to the farmer, excited the attention they deserved, or produced any immediate effect on the progress of agriculture. It was not till the year 1812 that the interest of practical men was fairly awakened by a course of lectures given by Sir Humphrey Davy, at the instance of Sir John Sinclair, who was at that time president of the Board of Agriculture. In these lectures, written with all the clearness and precision which characterised their author's style, the results of De Saussure's experiments were for the first time presented to the farmer in a form in which they could be easily understood by him, the conclusions to which they led were distinctly indicated, and a number of useful practical suggestions made, many of which have been adopted into every-day practice, and become so thoroughly incorporated with it, that their scientific origin has been altogether forgotten. A lively interest was excited by the publication of Davy's work, but it soon died out, and the subject lay in almost complete abeyance for a considerable number of years. Nor could any other result be well expected, for at that time agriculture was not ripe for chemistry, nor chemistry ripe for agriculture. The necessities of a rapidly increasing population had not yet begun to compel the farmer to use every means adapted to increase the amount of production to its utmost limit; and though the fundamental principles of chemistry had been established, its details, especially in that department which treats of the constituents of plants and animals, were very imperfectly known. It is not surprising, therefore, that matters should have remained almost unchanged for the comparatively long period of nearly thirty years. Indeed, with the exception of the investigation of soils by Schübler, and some other inquiries of minor importance, and which, in this country at least, excited no attention on the part of the agriculturist, nothing was done until the year 1840, when Liebig published his treatise on *Chemistry, in its application to Agriculture and Physiology*.

Saussure's researches formed the main groundwork of Liebig's treatise, as they had before done for Davy's; but the progress of science had supplied many new facts which confirmed the opinions of the older chemists in most respects, and enabled Liebig to generalise with greater confidence, and illustrate more fully the principles upon which chemistry ought to be applied to agriculture. Few works have ever produced a more profound impression. Written in a clear and forcible style, dealing with scientific truths in a bold and original manner, and producing a strong impression, as well by its earnestness as by the importance of its conclusions, it was received by the agricultural public with the full conviction that the application of its principles was to be immediately followed by the production of immensely increased crops, and by a rapid advance in every branch of practical agriculture. The disappointment of these extravagant expectations, which *chemists* themselves foresaw, and for which they vainly attempted to prepare the agriculturist, was followed by an equally rapid reaction; and those who had embraced Liebig's views, and lauded them as the commencement of a new era, but who had absurdly expected an instantaneous effect, changed their opinion, and contemned, as strongly as they had before supported, the application of chemistry to agriculture.

That this effect should have been produced is not unnatural; for practical men, having at that time little or no knowledge of chemistry, were necessarily unable to estimate its true position in relation to agriculture, and forgetting that this department of science was still in its early youth, and burthened with all the faults and errors of youth, they treated it as if it were already perfect in all its parts. Neither could they distinguish between the fully demonstrated scientific truths, and the uncertain, though probable conclusions deduced from them; and when the latter, as occasionally happened, proved to be at variance with practice, it is not surprising: that this should have produced a feeling of distrust on the part of persons incapable, from an imperfect, and still oftener from no knowledge of science, of drawing the line of demarcation, which Liebig frequently omitted to do, between the positive fact and the hypothetical inference, which, however probable, is, after all, merely a suggestion requiring to be substantiated by experiment. This omission, which the scientific reader can supply for himself, becomes a source of serious misapprehension in a work addressed to persons unacquainted with science, who adopt indiscriminately both the facts and the hypotheses of the author. And this is no doubt the cause of the vary different estimation in which the work of the Giessen Professor was held by scientific and practical men.

Liebig's treatise was followed, in the year 1844, by the publication of Boussingault's *Economic Rurale*, a work winch excited at the time infinitely less interest than Liebig's, although it is really quite as important a contribution to scientific agriculture. It is distinguished by entering more fully into the special details of the application of chemistry to agriculture, and contains the results of the author's numerous searches both in the laboratory and the field. Boussingault possesses the qualification, at present somewhat rare, of combining a thorough knowledge of practical agriculture with extended scientific attainments; and his investigations, which have been made with direct reference to practice, and their results tested in the field, are the largest and most valuable contribution to the exact data of scientific agriculture which has yet been made public.

The year 1844 was also distinguished by the foundation of the Agricultural Chemistry Association of Scotland, an event of no small importance in the history of scientific agriculture. That association was instituted through the exertions of a small number of practical farmers, for the purpose of pursuing investigations in agricultural chemistry, and affording to its members assistance in all matters connected with the cultivation of the soil, and has formed the model of similar establishments in London, Dublin, and Belfast, as well as in Germany; and it is peculiarly creditable to the intelligence and energy of the practical farmers of Scotland, that with them commenced a movement, which has already found imitators in so many quarters, and conferred such great benefits on agriculture. Within the last ten or twelve years, and mainly owing to the establishment of agricultural laboratories, great progress has been made in accumulating facts on which to found an accurate knowledge of the principles of agricultural chemistry, and the number of chemists who have devoted themselves to this subject has considerably increased, though still greatly less than its exigencies require.

Notwithstanding all that has recently been done, it must not be forgotten that we have scarcely advanced beyond the threshold, and that it is only by numerous and frequently repeated experiments that it is possible to arrive at satisfactory results. Agricultural inquiries are liable to peculiar fallacies due to the perturbing influence of climate, season, and many other causes, the individual effects of which can only be eliminated with difficulty, and much error has been introduced, by hastily generalising from single experiments, in place of awaiting the results of repeated trials. Hence it is that the progress of scientific agriculture must necessarily be slow and gradual, and is not likely to be marked by any great or startling discoveries. Now that the relations of science to practice are better understood, the extravagant expectations at one time entertained have been abandoned, and, as a necessary consequence, the interest in agricultural chemistry has again increased, and the conviction daily gains ground that no one who wishes to farm with success, can afford to be without some knowledge of the scientific principles of his art.

CHAPTER I.

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THE ORGANIC CONSTITUENTS OF PLANTS.

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When the water naturally existing in plants is expelled by exposure to the air or a gentle heat, the residual dry matter is found to be composed of a considerable number of different substances, which have been divided into two great classes, called the organic and the inorganic, or mineral constituents of plants. The former are readily combustible, and on the application of heat, catch fire, and are entirely consumed, leaving the inorganic matters in the form of a white residuum or ash. All plants contain both classes of substances; and though their relative proportions vary within very wide limits, the former always greatly exceed the latter, which in many cases form only a very minute proportion of the whole weight of the plant. Owing to the great preponderance of the organic or combustible matters, it was at one time believed that the inorganic substances formed no part of the true structure of plants, and consisted only of a small portion of the mineral matters of the soil, which had been absorbed along with their organic food; but this opinion, which probably was never universally entertained, is now entirely abandoned, and it is no longer doubted that both classes of substances are equally essential to their existence.

Although they form so large a proportion of the plant, its organic constituents are composed of no more than four elements, viz.:—

Carbon.
Hydrogen.
Nitrogen.
Oxygen.

The inorganic constituents are much more numerous, not less than thirteen substances, which appear to be essential, having been observed. These are—

Potash.
Soda.
Lime.
Magnesia.
Peroxide of Iron.
Silicic Acid.
Phosphoric Acid.
Sulphuric Acid.
Chlorine.

And more rarely

Manganese.
Iodine.
Bromine.
Fluorine.

Several other substances, among which may be mentioned alumina and copper, have also been enumerated; but there is every reason to believe that they are not essential, and the cases in which they have been found are quite exceptional.

It is to be especially noticed that none of these substances occur in plants in the free or uncombined state, but always in the form of compounds of greater or less complexity, and extremely varied both in their properties and composition.

It would be out of place, in a work like the present, to enter into complete details of the properties of the elements of which plants are composed, which belongs strictly to pure chemistry, but it is necessary to premise a few observations regarding the organic elements, and their more important compounds.

Carbon.—When a piece of wood is heated in a close vessel, it is charred, and converted into charcoal. This charcoal is the most familiar form of carbon, but it is not absolutely pure, as it necessarily contains the ash of the wood from which it was made. In its purest form it occurs in the diamond, which is believed to be produced by the decomposition of vegetable matters, and it is there crystallized and remarkably transparent; but when produced by artificial processes, carbon is always black, more or less porous, and soils the fingers. It is insoluble in water, burns readily, and is converted into carbonic acid. Carbon is the largest constituent of plants, and forms, in round numbers, about 50 per cent of their weight when dry.

Carbonic Acid.—This, the most important compound of carbon and oxygen, is best obtained by pouring a strong acid upon chalk or limestone, when it escapes with effervescence. It is a colourless gas, extinguishing flame, incapable of supporting respiration, much heavier than atmospheric air, and slightly soluble in water, which takes up its own volume of the gas. It is produced abundantly when vegetable matters are burnt, as also during respiration, fermentation, and many other processes. It is likewise formed daring the decay of animal and vegetable matters, and is consequently evolved from dung and compost heaps.

Hydrogen occurs in nature only in combination. Its principal compound is water, from which it is separated by the simultaneous action of an acid, such as sulphuric acid and a metal, in the form of a transparent gas, lighter than any other substance. It is very combustible, burns with a pale blue flame, and is converted into water. It is found in all plants, although in comparatively small quantity, for, when dry, they rarely contain more than four or five per cent. Its most important compound is water, of which it forms one-ninth, the other eight-ninths consisting of oxygen.

Nitrogen exists abundantly in the atmosphere, of which it forms nearly four-fifths, or, more exactly, 79 per cent. It is there mixed, but not combined with oxygen; and when the latter gas is removed, by introducing into a bottle of air some substance for which the former has an affinity, the nitrogen is left in a state of purity. It is a transparent gas, which is incombustible and extinguishes flame. It is a singularly inert substance, and is incapable of directly entering into union with any other element except oxygen, and with that it combines with the greatest difficulty, and only by the action of the electric spark—a peculiarity which has very important bearings on many points we shall afterwards have to discuss. Nitrogen is found in plants to the extent of from 1 to 4 per cent.

Nitric Acid.—This, the most important compound of nitrogen and oxygen, can be produced by sending a current of electric sparks through a mixture of its constituents, but in this way it can be obtained only in extremely small quantity. It is much more abundantly produced when organic matters are decomposed with free access of air, in which case the greater proportion of their nitrogen combines with the atmospheric oxygen. This process, which is known by the name of nitrification, is greatly promoted by the presence of lime or some other substance, with which the nitric acid may combine in proportion as it is formed. It takes place, to a great extent, in the soil in India and other hot climates; and our chief supplies of saltpetre, or nitrate of potash, are derived from the soil in these countries, where it has been formed in this manner. The same change occurs, though to a much smaller extent, in the soil in temperate climates.

Ammonia is a compound of nitrogen and hydrogen, but it cannot be formed by the direct union of these gases. It is a product of the decomposition of organic substances containing nitrogen, and is produced when they are distilled at a high temperature, or allowed to putrefy out of contact of the air. In its pure state it is a transparent and colourless gas, having a peculiar pungent smell, and highly soluble in water. It is an alkali resembling potash and soda, and, like these substances, unites with the acids and forms salts, of which the sulphate and muriate are the most familiar. In these salts it is fixed, and does not escape from them unless they be mixed with lime, or some other substance possessing a more powerful affinity for the acid with which it is united.

Oxygen is one of the most widely distributed of all the elements, and, owing to its powerful affinities, is the most important agent in almost all natural changes. It is found in the air, of which it forms 21 per cent, and in combination with hydrogen, and almost all the other chemical elements. In the pure state it possesses very remarkable properties. All substances burn in it with greater brilliancy than they do in atmospheric air, and its affinity for most of the elements is extremely powerful. When diluted with nitrogen, it supports the respiration of animals; but in the pure state it proves fatal after the lapse of an hour or two. It is found in plants, in quantities varying from 30 to 36 per cent.

It is worthy of observation, that of the four organic elements, carbon only is fixed, and the other three are gases; and likewise, when any two of them unite, their compound is either a gaseous or a volatile substance. The charring of organic substances, which is one of their most characteristic properties, and constantly made use of by chemists as a distinctive reaction, is due to this peculiarity; for when they are heated, a simpler arrangement of their particles takes place, the hydrogen, nitrogen, and oxygen unite among themselves, and carry off a small quantity of carbon, while the remainder is left behind in the form of charcoal, and is only consumed when access of the external air is permitted.

Now, in order that a plant may grow, its four organic constituents must be absorbed by it, and that this absorption may take place, it is essential that they be presented to it in suitable forms. A seed may be planted in pure carbon, and supplied with unlimited quantities of hydrogen, nitrogen, oxygen, and inorganic substances, and it will not germinate; and a plant, when placed in similar circumstances, shows no disposition to increase, but rapidly languishes and dies. The obvious inference from these facts is, that these substances cannot be absorbed when in the *elementary* state, but that it is only after they have entered into certain forms of combination that they acquire the property of being readily taken up, and assimilated by the organs of the plant.

It was at one time believed that many different compounds of these elements might be absorbed and elaborated, but later and more accurate experiments have reduced the number to four—namely, carbonic acid, water, ammonia, and nitric acid. The first supplies carbon, the second hydrogen, the two last nitrogen, while all of them, with the exception of ammonia, may supply the plant with oxygen as well as with that element of which it is the particular source.

There are only two sources from which these substances can be obtained by the plant, viz. the atmosphere and the soil, and it is necessary that we should here consider the mode in which they may be obtained from each.

The Atmosphere as a source of the Organic Constituents of Plants.—Atmospheric air consists of a mixture of nitrogen and oxygen gases, watery vapour, carbonic acid, ammonia, and nitric acid. The two first are the largest constituents, and the others, though equally essential, are present in small, and some of them in extremely minute quantity. When deprived of moisture and its minor constituents, 100 volumes of air are found to contain 21 of oxygen and 79 of nitrogen. Although these gases are not chemically combined in the air, but only mechanically mixed, their proportion is exceedingly uniform, for analyses completely corresponding with these numbers have been made by Humboldt, Gay-Lussac, and Dumas at Paris, by Saussure at Geneva, and by Lewy at Copenhagen; and similar results have also been obtained from air collected by Gay-Lussac during his ascent in a balloon at the height of 21,430 feet, and by Humboldt on the mountain of Antisano in South America at a height of 16,640 feet. In short, under all circumstances, and in all places, the relation subsisting between the oxygen and nitrogen is constant; and though, no doubt, many local circumstances exist which may tend to modify their proportions, these are so slow and partial in their operations, and so counterbalanced by others acting in an opposite direction, as to retain a uniform proportion between the main constituents of the atmosphere, and to prevent the undue accumulation of one or other of them at any one point.

No such uniformity exists in the proportion of the minor constituents. The variation in the quantity of watery vapour is a familiar fact, the difference between a dry and moist atmosphere being known to the most careless observer, and the proportions of the other constituents are also liable to considerable variations.

Carbonic Acid.—The proportion of carbonic acid in the air has been investigated by Saussure. From his experiments, made at the village of Chambeisy, near Geneva, it appears that the quantity is not constant, but varies from 3·15 to 5·75 volumes in 10,000; the mean being 4·15. These variations are dependent on different circumstances. It was found that the carbonic acid was always more abundant during the night than during the day—the mean quantity in the former case being 4·32, in the latter 3·38. The largest quantity found during the night was 5·74, during the day 5·4. Heavy and continued rain diminishes the quantity of carbonic acid, by dissolving and carrying it down into the soil. Saussure found that in the month of July 1827, during the time when nine millimetres of rain fell, the average quantity of carbonic acid amounted to 5·18 volumes in 10,000; while in September 1829, when 254 millimetres fell, it was only 3·57. A moist state of the soil, which is favourable to the absorption of carbonic acid, also diminishes the quantity contained in the air, while, on the other hand, continued frosts, by retaining the atmosphere and soil in a dry state, have an opposite effect. High winds increase the carbonic acid to a small extent. It was also found to be greater over the cultivated lands than over the lake of Geneva; at the tops of mountains than at the level of the sea; in towns than in the country. The differences observed in all these cases, though small, are quite distinct, and have been confirmed by subsequent experimenters.

Ammonia.—The presence of ammonia in the atmosphere appears to have been first observed by Saussure, who found that when the sulphate of alumina is exposed to the air, it is gradually converted into the double sulphate of alumina and ammonia. Liebig more recently showed that ammonia can always be detected in rain and snow water, and it could not be doubted that it had been absorbed from the atmosphere. Experiments have since been made by different observers with the view of determining the quantity of atmospheric ammonia, and their results are contained in the subjoined table, which gives the quantity found in a million parts of air.

Kemp			3·6800
Pierre	12 feet above the surface		3·5000
	25 feet do. do.		0·5000
Graeger			0·3230
Fresenius	By day		0·0980
	By night		0·1690
Ville	In Paris	Maximum	0·0317
		Minimum	0·0177
		Mean	0·0237
	Environs of Paris	Maximum	0·0276
		Minimum	0·0165
		Mean	0·0210

Of these results, the earlier ones of Kemp, Pierre, and Graeger are undoubtedly erroneous, as they were made without those precautions which subsequent experience has shown to be necessary. Even those of the other observers must be taken as giving only a very general idea of the quantity of ammonia in the air, for a proportion so minute as one fifty-millionth cannot be accurately determined even by the most delicate experiments. For this reason, more recent experimenters have endeavoured to arrive at conclusions bearing more immediately upon agricultural questions, by determining the quantity of ammonia brought down by the rain. The first observations on this subject were made by Barral in 1851, and they have been repeated during the years 1855 and 1856 by Mr. Way. In 1853, Boussingault also made numerous experiments on the quantity of ammonia in the rain falling at different places, as well as in dew and the moisture of fogs. He found in the imperial gallon—

			Grs.
Rain	Paris		0·2100
	Liebfrauenberg		0·0350
Dew,	Liebfrauenberg	Maximum	0·4340
		Minimum	0·0714
Fog	Liebfrauenberg		0·1790
	Paris		9·6000

It thus appears that in Paris the quantity of ammonia in rain-water is just six times as great as it is in the country, a result, no doubt, due to the ammonia evolved during the combustion of fuel, and to animal exhalations, and to the same cause, the large quantity contained in the moisture of fogs in Paris may also be attributed. Barral and Way have made determinations of the quantity of ammonia carried down by the rain in each month of the year, the former using for this purpose the water collected in the rain-gauges of the Paris Observatory, and representing, therefore, a town atmosphere; the latter, that from a large rain-gauge at Rothamsted, at a distance from any town. According to Barral the ammonia annually deposited on an acre of land amounts to 12·28 lbs., a quantity considerably exceeding that obtained by Way, whose experiments being made at a distance from towns, must be considered as representing more accurately the normal condition of the air. His results for the years 1855 and 1856 are given below, along with the quantities of nitric acid found at the same time.

Nitric Acid.—The presence of nitric acid in the air appears to have been first observed by Priestley at the end of the last century, but Liebig, in 1825, showed that it was always to be found after thunder-storms, although he failed to detect it at other times. In 1851 Barral proved that it is invariably present in rain-water, and stated the quantity annually carried down to an acre of land at no less than 41·29 lbs.

But at the time his experiments were made, the methods of determining very minute quantities of nitric acid were exceedingly defective, and Way, by the adoption of an improved process, has shown that the quantity is very much smaller than Barral supposed, and really falls short of three pounds. His results for ammonia, as well as nitric acid, are given in the subjoined table.

	Nitric Acid in Grains.		Ammonia in Grains.		Total Nitrogen in Grains.	
	1855.	1856.	1855.	1856.	1855.	1856.
January	230	1564	1244	5,005	1084	4,526
February	944	544	2337	4,175	2169	3,579
March	1102	866	4513	2,108	3995	1,945
April	325	1063	1141	8,614	1024	7,369
May	1840	3024	4206	18,313	3939	15,863
June	3303	2046	5574	4,870	5447	4,540
July	2680	1191	9620	2,869	8615	2,670
August	3577	2125	4769	4,214	4870	4,021
September	732	1756	3313	5,972	2917	5,373
October	4480	2075	7592	3,921	7414	3,767
November	1007	1371	3021	2,591	2749	2,489
December	664	2035	2438	4,070	2180	3,352
Total in pounds for the whole year	2·98	·280	7·11	9·53	6·63	8·31

No attempts have been made to determine the proportion of nitric acid in air, but its quantity is undoubtedly excessively minute, and materially smaller than that of ammonia. At least this conclusion seems to be a fair inference from Way's researches, as well as the recent experiments of

Boussingault on the proportion of nitric acid contained in rain, dew, and fog, made in a manner exactly similar to those on the ammonia, already quoted. According to his experiments an imperial gallon contains—

		Grs.
Rain.	{Paris	0·0708
	{Liebfrauenberg	0·0140
Dew.	{Maximum	0·0785
	{Minimum	0·0030
Fog.	{Paris	0·7092
	{Liebfrauenberg	0·0718

Although it thus appears that Barral's results have been only partially confirmed, enough has been ascertained to show that the quantity of ammonia and nitric acid in the air is sufficient to produce a material influence in the growth of plants. The large amount of these substances contained in the dew is also particularly worthy of notice, and may serve to some extent to explain its remarkably invigorating effect on vegetation.

Carburetted Hydrogen.—Gay-Lussac, Humboldt, and Boussingault have shown, that when the whole of the moisture and carbonic acid have been removed from the air, it still contains a small quantity of carbon and hydrogen; and Saussure has rendered it probable that they exist in a state of combination as carburetted hydrogen gas. No definite proof of this position has, however, as yet been adduced, and the function of the compound is entirely unknown. It is possible that the presence of carbon and hydrogen may be due to a small quantity of organic matter; but, whatever be its source, its amount is certainly extremely small.

Sulphuretted Hydrogen and Phosphuretted Hydrogen.—The proportion of these substances is almost infinitesimal; but they are pretty general constituents of the atmosphere, and are apparently derived from the decomposition of animal and vegetable matters.

The preceding statements lead to the important conclusion, that the atmosphere is capable of affording an abundant supply of all the organic elements of plants, because it not only contains nitrogen and oxygen in the free state, but also in those forms of combination in which they are most readily absorbed, as well as a large quantity of carbonic acid, from which their carbon may be derived. At first sight it may indeed appear that the quantity of the latter compound, and still more that of ammonia, is so trifling as to be of little practical importance. But a very simple calculation serves to show that, though relatively small, they are absolutely large, for the carbonic acid contained in the whole atmosphere amounts in round numbers to

2,400,000,000,000 tons,

and the ammonia, assuming it not to exceed one part in fifty millions, must weigh

74,000,000 tons,

quantities amply sufficient to afford an abundant supply of these elements to the whole vegetation of our globe.

The Soil as a Source of the Organic Constituents of Plants.—When a portion of soil is subjected to heat, it is found that it, like the plant, consists of a combustible and an incombustible part; but while in the plant the incombustible part or ash is small, and the combustible large, these proportions are reversed in the soil, which consists chiefly of inorganic or mineral matters, mixed with a quantity of combustible or organic substances, rarely exceeding 8 or 10 per cent, and often falling considerably short of this quantity.

The organic matter exists in the form of a substance called humus, which must be considered here as a source of the organic constituents of plants, independently of the general composition of the soil, which will be afterwards discussed.

The term *humus* is generic, and applied by chemists to a rather numerous group of substances, very closely allied in their properties, several of which are generally present in all fertile soils. They have been submitted to examination by various chemists, but by none more accurately than by Mulder and Herman, to whom, indeed, we owe almost all the precise information we possess on the subject. The organic matters of the soil may be divided into three great classes; the first containing those substances which are soluble in water; the second, those extracted by means of caustic potash; and the third, those insoluble in all menstrua. When a soil is boiled with a solution of caustic potash, a deep brown fluid is obtained, from which acids precipitate a dark brown flocculent substance, consisting of a mixture of at least three different acids, to which the names of humic, ulmic, and geic acids have been applied. The fluid from which they have been precipitated contains two substances, crenic and apocrenic acids, while the soil still retains what has been called insoluble humus.

The acids above named do not differ greatly in chemical characters, but they have been subdivided into the humic, geic, and crenic groups, which present some differences in properties and composition. They are compounds of carbon, hydrogen, and oxygen, and are characterised by so powerful an affinity for ammonia that they are with difficulty obtained free from that substance, and generally exist in the soil in combination with it. They are all products of the decomposition of vegetable matters in the soil, and are formed during their decay by a succession of changes, which may be easily traced by observing the course of events when a piece of wood or any other vegetable substance is exposed for a length of time to air and