Chapter

Opening History: Gaining Perspectives

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Abstract

After Second World War, historical agricultural systems that gave pivotal roles to organics were effectively locked away, with a warning on the door 'Liebig disproved it all!'. The recent digitalisation of a vast amount of historical literature gave us the key to unlock the door. It opens not to a dusty archive but to a land with great treasures. Entering it we regain a perspective on the pivotal roles of organics in agriculture but not without effort. We lost contact with the soil when after Second World War, we denied farmers' practices and focussed at fertiliser industry instead. Proud of our construct, 'modern agriculture', we nevertheless positioned the statue of Liebig the frightening warrior in front. It is not easy to get rid of a mix of pride and fear. Still, historical evaluation helps us to uncover what was hidden and equips us to rediscover the roles of ever-local organics as administered by local farmers.

Keywords: Liebig, peer review, soil quality, mixotrophy, mineral solubilisation, De Saussure, post-war policy, legumes, Olsen P test, extended N- and P-cycles, modelling

1. Introduction[1]

The eighteenth and nineteenth centuries were very rich in agricultural literature, and very much of it is relevant as to the subject of the present volume. Yet, nearly all of this literature has been consistently neglected after Second World War. No doubt the reader knows the one-liner 'Liebig disproved Thaer's humus theory of plant nutrition and proved mineral nutrition instead, then with the introduction of industrial fertilisers crop yields could grow steeply'. Now although one-liners cannot make up for history, they still can induce the neglect of historical sources, and exactly that happened when the Liebig one-liner was used to sideline the roles of organics in agriculture and plant nutrition. Historian Frank Uekötter (now in Birmingham) took a close look at the period between the World Wars and after Second World War and showed that as to agriculture and soil, an all-out 'knowledge erosion' occurred (See his 500+ pp. 2010/2012 *The truth is in the field*—in German). When we go further back in history, it becomes clear that Liebig himself was at the roots of this 'knowledge erosion'.

[1] The present contribution embodies original historical research so there are no reviews yet, and we have to list the original sources. The historiographic approach used here has its roots in the work of the prominent science historian Reyer Hooykaas († 1993), while the recent Leiden PhD theses of Karstens [162] and Bouterse [163] give expositions of its 'evaluative historiography'. See for Uekötter's free-access publications on the loss of history in agronomics [164–169].

2. Reconsidering the Liebig thesis

We know from his correspondence with the leading chemist Berzelius that Liebig started his first experiments in crops growing only in 1841, a year after he published his *Chemistry in its application to agriculture and physiology*. Berzelius asked him the details of the experiments but never received them [1]. Yet, in the 1850s Liebig prescribed the setup of experiments and their analysis in the Bavarian agricultural experiment station. At the core of it was, *first*, his equation of 'elements' and 'nutrients' and, *second*, his denial of mineral-organic interactions. The first was a misnomer also in 1840 but was backed up by the 'element juggling' that was at the core of Liebig's plant physiology and physiology at large (remember he denied enzymatic catalysis and catalysis at large). The second was at variance with a very long time of agricultural experience. Yet, in combination they suggested that something completely transparent—the nutrient element construct—now could guide agriculture in its dealings with soils and crops, and it was this that was difficult to resist in these high days of rationalism (on this see [2]).

Note also that the search for a 'fertilising principle' had a long history already. With saltpetre known for centuries, its quick action in plant growth stimulation was discovered early and brought some authors to its identification with the 'fertilising principle'. Early in the nineteenth century, there had been some regional efforts in France as well as in England to use it in agriculture, but these had soon been abandoned because of lodging and plant disease problems. Most farmers were at pains to build soil quality (see later), aware that there were no 'fertilising principles' offering a short cut. Once soil quality was achieved, some kind of 'fermentation' was thought to have a role in mobilising plant nutrients.

But then in the middle decades of the nineteenth century, interregional and international transport grew strongly, and especially with guano supply, the old dream of fertilising principles seemed to materialise. It was in these decades that the 'clearness' of the Liebig concepts and methods stood out against the high complexity of soil and soil organics. The picture was seductively clear: analyse your soil for abundant and scarce 'nutrient elements', analyse your crops for those elements removed, resupply them in your mineral fertiliser, and the problem of 'soil exhaustion' is no more. The only role of organics was that of suppliers of mineral nutrients and carbon dioxide on decomposition.

Still, common experience first of all in vegetable gardens had established the value of soil organics and of the extract of garden soil to crop growth. And so the *Société centrale d'agriculture de Rouen* at the end of the 1840s came with a price contest about the subject. Soubeiran won the contest with his essay 'Chemical analysis of humus and role of manure in plant nutrition' [3, 4]. In accordance with De Saussure 1841, he proved that dilute ammonia dissolved an important part of the soil organics and stressed that ammonium carbonate deriving from disintegrating manures had the same effect. This solubilised part of 'humus' then entered the plant. The fact that the plant derives most of its carbon from the atmosphere was not to deny the importance of humus uptake, 'for if the absorbed humus gives effectively a nutrition that increases the plant's vitality, and that causes the number and volume of absorbing organs to increase, the plant will derive much more from the atmosphere. The humus, without having provided all of the carbon, will nevertheless be the effective cause of the abundant production of wood and other parts of the plant'.

This plant growth promotion aspect of humic extracts from fertile soil was accepted also by researchers who doubted true assimilation of humics. Soubeiran made careful experiments, emphasised the many valuable functions of humus, and gave close consideration of manures and their interaction with humus [5]. Malaguti, the leading French chemist known also for his work on agricultural chemistry, followed on the Soubeiran experiment and used the balance to prove the humus uptake [6]. Then in 1862 Corenwinder [7] showed carbon dioxide uptake by roots to be unimportant (as a rule), thus disproving Liebig's explanation for plant growth stimulation by humics. So research into the connections between crop growth and soil organics continued, with Eugene Risler from Switzerland soon followed by Pierre-Paul Dehérain in France and Ewald Wollny in Germany.

Yet, for some time the Liebig approach stayed dominant for it had been 'institutionalised' in most of the agricultural experiment stations, with their directors often from the Liebig school and quite uncritical to the Liebig doctrines. E. Wolff's *The natural law foundations of agriculture* [8] offers us an example. Jacob Johnson, a leading agronomist from (then) Russia, compared it with historical and experimental reality and found it wanting on both points [9]. When Wolff from the possibility to grow certain plants in mineral nutrient solution 'proved' the non-uptake of humics, Johnson remarked: 'So because we do not provide them with humics, therefore they cannot take it up and assimilate it! No doubt that is right; a man also cannot eat bread and digest it when he has none!'.

Leading scientists like Johnson [9, 10] and Risler [11, 12] reminded Liebig and his followers of historical agronomy. Although they published in leading journals, they had little response. Liebig's followers made their own accounts, e.g. [13]. That author is very selective in his sources, gives citations that are one-sided (e.g. about Thaer), and misses out on most of the leading agronomic publications from the eighteenth and nineteenth centuries. In fact, such an account is worse than no account. But organic practices were still part and parcel of agriculture and also in agricultural experiment stations and soon field experiments brought renewed attention to the importance of organics (e.g. Dehérain's and Wollny's research). Toward the end of the century, we see the Liebig doctrines losing their grip on the minds, not unlike what happened with his concepts and methods in physiology. Still, if we look at the 1840s, Liebig's influence could have been of much shorter duration.

The agronomist of great standing Schmalz [14] in 1841 published his 'To Julius: An open letter to Justus von Liebig' that makes clear how complex the discipline is on which Liebig wanted to impose his 'science' [15]. This followed on Liebig's 1841 [16] cross 'rebuttal' of Carl Sprengel's review [17] of Liebig's 1840 book [18] that, in conformance with his earlier work on humics [19], started with emphasising the roles of humics in plant growth and nutrition. Note that Sprengel's authority as editor of the (Prussian) *General Agricultural Monthly* derived from his thorough acquaintance with both agriculture and soil chemistry, so people now asked 'Sprengel or Liebig?'. To bring the discussion at the required level, Schmalz wrote *Aphorisms from plant nutrition learning* [20] in which he focussed, also from own experiments with nettle, more specifically on crop nutrition. But Liebig did not respond.

In those same years, Liebig's denial [21] of the roles of organics in plant nutrition, as against Théodore De Saussure's proofs [22, 23], was questioned by leading biologists of the age (von Mohl, Fürnrohr, Schlechtendal). When Trinchinetti's [24] as well as Jacob Johnson's [25] experiments corroborated those of De Saussure, the matter was settled, and Schlechtendal wrote: 'So it seems that Sprengel's teaching ….is right, yet unfounded Liebig's thesis that humus provides the plants only carbonic acid' [26, 27]. Note that Liebig in the 5th edition of his book mended many of the botanical and other faults that Hugo von Mohl had listed in his 1843 *Dr Justus Liebig's relation to plant physiology* [28]. He even removed the account of forester Hartig's experiments—all experiments he had (De Saussure had indicated Hartig had injured the roots of his plants). But von Mohl's [28] primary objection that he did not use the means available to him as a chemist to study the subject experimentally did not move him to an experimental approach. von Mohl predicted [29] that also the 5th edition would lead many astray because 'it lacks any and all historical account'. Liebig kept silent about it all including the *peer review* conclusion (see also [30]), but note that Hugo von Mohl [31] maintained the final verdict in his famous *Principles of the anatomy and physiology of the vegetable cell*.

Still, we see Liebig later in the 1840s hesitating (in a letter to Wöhler, see [32]) about further involvement with agriculture. Leading authors like Petit-Lafitte [33, 34], Schubert [35], and Fresenius [36] still emphasised organic uptake by plants (note Remigius Fresenius was the leading authority in analytical chemistry). Note also that Liebig's best student Adolf Strecker in 1848 acquired the *Venia legendi* with his researches about the chemical constitution of oxen bile [37], with one of the theses accompanying the account [38] 'Organic substances are nutrients for plants'. By then Liebig's patented mineral fertiliser had proved to be a failure [39], factually disproving his 'minerals-only' doctrine. Moreover in 1847 the Prussian Agricultural Council initiated an interlaboratory round for the determination of mineral nutrients in soils in connection with plant uptake and found it outside the possibilities of chemistry [40]. *First*, the changes in question, as calculated from the total mineral contents of the crop plants covering the field divided by the field's arable soil volume, were within measurement error (they would say so). *Second*, the differences in determinations (of in-soil quantities) between laboratories were excessive, a problem that would haunt such determinations for the rest of the century (and later). The Liebig model of crop nutrition, though 'claire et distincte', proved chemically unworkable when confronted with real soils.

But the 1840s were a decade of famine and revolution, not a decade in which careful study and evaluation decided about the events. Moreover many scientists of the old guard died in those years—Berzelius, Schwerz, de Saussure, Schwann, and quite some others—and the transfer of their roles in 'peer review' to younger scientists proved complicated enough. Liebig managed to draw that role to himself in connection with laboratory chemistry and then used this authority to once more give his judgements about bordering disciplines. In due time his opinion of catalysis, fermentation, and many medical subjects proved mistaken, and by the end of the century, his contributions to these fields were mostly passed over quietly. But in such disciplines, his opinions were discussed besides those of others; they did not shape the field, and so in due time, Liebig's errors could show up (cp. Pasteur's experiment disproving Liebig's abiotic theory of fermentation).

As it was, after the lingering indicated, we see from 1850 on Liebig renewing his efforts to impose his 'science' on agriculture. His public fame depended on it, including his fame with the king of Bavaria who called him to Munich. Leading agronomists compared statements and generalisations of Liebig and his followers with real-life and historical agriculture, e.g. [9–12, 41–46]. It was to no avail because Liebig did not respond but constructed his division of 'agronomy before 1840 vs agronomy after it' instead (it found its way into the Liebig one-liner). And he reverted to his former cross approach, with 'fire and the sword' [47], replacing scientific discussions. When Mulder in 1865 published this three-volume overview of agriculture and agricultural chemistry [48]—the best of those decades according to van Bemmelen 1901 [49]—Liebig did not enter into discussion at all but instead wrote with biting sarcasm about Mulder. The way in which he in those same years managed to silence the very learned Fraas was still more infame. Fraas' *Book of Nature for Farmers* [50] for a broad public as well as his *The root life of crop plants and the increase of yields*' [51] had no equals in those years ([51] is still very profitable to read).

There is, in short, ample reason *not* to take Liebig as our guide. But high-level researchers in those years who were well-versed in both the agriculture of their age and in supporting disciplines we can take as our guide in restoring the history of agronomy in the second half of the nineteenth century including the subject of soils, organics, and crop nutrition. Now with the Liebig's stop sign removed, we of course start wondering about the wider history too. We will see that the farmers' knowledge of their soils can be our guide.

3. Soil quality as baseline

Estienne et al. [52] in the paragraph *About ground and soil of an estate* give a short list of characteristics of a fertile soil (S. 33): (1) A strong rain does not lead to mud; the ground drinks in the water and keeps it for a long time. (2) On a fertile soil, we meet a strong and dense vegetation (in the wild). (3) Its soil solution has a sweetish taste [see under]. (4) When we dig a hole, put the earth aside for 2 or 3 days, and then fill it again; a good soil will leave a small hill, a medium soil will just fill the hole, and a bad soil will leave a hollow. (5) With a good soil, the first rain after some drought in spring will give a pleasant odour. We find a similar list in [53–55]. Evidently also three or four centuries ago, farmers realised that—in our words—infiltration capacity and soil structure were characteristics of a good soil. The 'hole filling test' is part of the 'spade test' and fits in with other visual tests of our day [56–60]. The early authors took also good note of biological criteria, plant growth first of all. The 'sweetish taste' of the soil solution from fertile soils they considered connected with soil quality and plant nutrition—and indeed soil carbohydrates are central to both micro-aggregate formation and mineral solubilisation.

The same or a strongly similar list appears in other early books on agriculture or horticulture. Heresbach/Googe [61] adds still another biological indicator: birds following the ploughman to feed upon worms, etc. We find closely similar lists in [62–64], the most extensive being [65]. As to the era before the printing press, Verena Winiwarter has given us some admirable overviews [66, 67], from which we learn that such a soil quality approach was known already in antiquity and Middle Ages. A core element of sustainable agriculture [68] it is its guide also when seeking to upgrade soils. Farmers in the past evidently had a notion of 'good soil' (and how to build it)—or they would not have survived [2]. These practical standards of experienced farmers and gardeners as to good soil are a backbone of agronomy throughout history.

In the eighteenth century, 'earths mixing' became a chief means to upgrade soils, with farm manure being the 'soul' of the mixture ([69], p. 118). Marling and chalking became widely known but were two examples of this general practice of 'mineral fertilisation'. The aim of it all was soil quality ([70], p. 15), but of course the diverse 'earths' brought also their own minerals with them. Pastor/agronomist Mayer tells us this 'earth mixing' originated with Swiss farmers at the beginning of the eighteenth century, farmers who had to be very careful with their soils [69]. Lüders [71] is all about research, evaluation, and use of the 'kinds of earths'; it is also the chief subject of [72] on general agronomy, and [73] gave an account of nearly 300 soil probes from all over the kingdom of Hannover (research committed by the government).

Mineral and organic components belonged together in this approach, something that was strengthened still by the general concept of *nutritious matter for plants*: *it consists, next to water, in fine earthen particles, fatty components, and salts* [74]. Most other authors used 'oils' for 'fatty components' but the meaning of it is clear: the concept of plant nutrition of these eighteenth-century authors fits closely to our concept of mixotrophy. There were of course differences between the chemistry, etc. of those authors and ours, but when we read Home's [75] chemical analysis of different soils with the means then available we see that we should not exaggerate these differences. What we as people from the twenty-first century need on background information, we can learn from [76].

But then from the latter decades of the eighteenth to the first decades of the nineteenth century, chemistry saw fast developments, best known from the name of Lavoisier, and agricultural chemistry partook of this 'turbulence'. But note it was not a backwater: Hermbstädt who translated all of Lavoisier's works in German was also the editor of the *Archive of Agricultural Chemistry* (in German), the first journal of its kind. From about 1820 on a less turbulent period set in, mixotrophy became quite broadly accepted again, now in terms of the new chemistry and in combination with photosynthesis. Two examples will do.

The leading agronomist Zierl (1797–1844) from Bayern in his 1830 *Plant Production* textbook [77] emphasised—critically following Carl Sprengel—the roles of humics in *solubilising mineral soil constituents* for plant uptake. This followed upon his acknowledgement of photosynthesis and the extensive treatment of mineral and organic plant nutrients. Zierl considered plants to have important roles in soil nutrient cycling, legumes in rotations with their long roots bringing nutrients in reach again of other crops. In conformance with earlier agronomy, Zierl maintained a soil quality approach.

That is true also of Johann Nepomuk Schwerz (1759–1845) who acquired his encyclopaedic knowledge of the art of agriculture especially on his many journeys on foot through regions of Belgium and Germany. He was conversant also with the life and practices of the small farmer (Thaer decidedly not). In his 1823 *Manual of Practical Agriculture* [78], he gave a summary of the crop nutrition knowledge of those years: 'So when indeed the plants derive their chief nutrition from the atmosphere and besides also from the residues of vegetable and animal bodies: it is not to deny that also mineral bodies, under which we count first of all the chalk, contribute to the growth of vegetables, and not just in stimulating, solubilising, manure-mediating roles, but also as true nutrients'. This mixotrophic approach was essentially maintained in the 2nd edition of Schwerz' manual that was published in 1837 and no doubt was available to Liebig.

At mid-nineteenth century, the soil quality approach was upheld as we see from a wide range of textbooks (including [79]). Next there is ongoing development especially in the *Progress in Soil Physics* series (1872 f.) that was edited by Ewald Wollny who also included reviews of soil biology in the serial. Wollny further developed the concept of Bodengare, 'active soil' (e.g. [80]) from a soil science point of view. Others then continued, with Johannes Görbing the best known author [81] (see also [82, 86]) and scientists like Sekera further developing theory and practice after Second World War [83, 84].

Soil quality as the leading concept was upheld also when the great agronomist and plant breeder Fruwirth in the 1921 edition of his textbook [85] specified 'main fertilisers' as those that were building the soil biologically, physically, and chemically, with farm manures and green manures the standard and others and especially mineral fertilisers as 'additional' only. When cheap nitrogen fertiliser in

Germany after First World War was pushed by the industry-government complex to remedy the large drop in yields that was a consequence of the war, it did more harm than good [86]. Again classical agronomy with its soil quality approach came to the rescue and showed the way to restore the soils and so the yields. Likewise it was the work of the Soil Conservation Service in the USA along the lines of classical agronomy and soil science that brought soil deterioration to a halt. For the past few decades, similar 'organic' approaches proved necessary to restore structurally deteriorated soils in Germany and to revive desertifying regions in Mediterranean countries.

4. Loss of history and quality

A core element of this soil quality approach was and is the use of legumes in agriculture. Research in legume use between the World Wars was greatly advanced by Fred and co-workers in the USA, by Thornton and Nicol in the UK, and especially by Virtanen in Finland (references in [87, 88]). Legumes were quite central to agriculture in parts of Finland and the Baltic countries, with coculture of peas and oats being a prominent part [89, 90]. Johnson [89] already concluded that the oats thriving in the coculture received nutrition from pea root exudates. In big parts of Latin America, farmers used the milpa system of coculture for ages already [91, 92]. In the USA the common farmer used legume rotations without N-fertilisers; industrial N-fertilisers were used by big landowners in the US South.

From the point of view of soil quality-based agriculture (and therefore of sustainable food provision), fertiliser-only agriculture was the wrong choice, so when Virtanen saw the latter policy coming, he wrote some reviews (in 1953) emphasising the advantages of legume use. Importantly it costs the common farmer only her labour and no money, and there were many poor farmers in Finland before and after Second World War, as there are now the world over. But with the takeover of the USDA by the Republicans at the 1942 elections, agricultural policy got redirected from its focus at the common farmer under the New Deal to its focus at large-scale agriculture as practised by the big landowners of the US South. After the war industrial N-fertiliser was offered at low prices—process facilities had been financed by the government in connection with explosive production for war—and was put at centre place in the new policies. With classical agronomy very critical of such a change, the 'Liebig doctrines' were advanced in its defence, so we turn once more to their historical origins.

De Saussure in 1841 lectured at the 9th Scientific Congress of France—that chose him as its president—about the question: 'The ternary and quaternary organic matters can they – or not – be assimilated by the plants, after being absorbed by their roots?'. He used the results of his own recent experiments to give an answer to this question. His slightly edited lecture he published already before the end of the year in the scientific monthly of his home town Geneva: '*What role is there for ternary and quaternary compounds in plant nutrition, not just the few binary ones mentioned by Liebig, considering that soil organics as a complex mixture of compounds could contribute to plant nutrition?*. So De Saussure stated the problem at chemical compound level, departing from the conflation of 'element' and 'nutrient' that had been quite common up till then. His conclusions were as follows: (1) fertile terrains contain a mixture of soluble and (mostly) insoluble organic substances, and uptake of the first by plant roots forms a powerful addition to the nutrients it receives from air and water [CO_2, H_2O], (2) a slow fermentation of the insoluble organic substances renews soluble organics, and (3) most plants do not assimilate gaseous nitrogen and receive only little ammonia from the air, so nearly all the N they contain is from absorption of soluble organic substances.

This could have been the start of the development of a true soil-plant N-cycle because it used **(a)** a chemically meaningful concept of 'nutrient' **(b)** linked to the soil by the use of the dynamic concept of 'humus' that had been around a long time already (and that included dynamic interactions with minerals in soils). But then Liebig forced a rupture by **(a)** reverting to the element-as-nutrient parlance and so disabling chemical research **(b1)** denying the need for organic fertilisers: well-growing plants would of themselves leave ample organics in the soil (later dubbed 'self-fertilising plants') **(b2)** denying also the diverse direct roles of soil organics in crop growth, so legitimating plant nutrition studies disconnected from the soil and using a minerals-only approach (as in the work of Knop, Sachs, and later Hoagland).

As indicated, after Second World War, the new agricultural policy was presented in terms of these 'Liebig doctrines'. Melsted, for example [93], wrote *Since 1950 the corn belt farmer has been able to choose whether to grow or buy his nitrogen*. But legumes were recommended as green manures for several reasons: *first* as soil builders and strongly so after the Dust Bowl of the 1930s and *next* as natural resource 'slow release fertilisers'. American farmers practised rotations with legumes instead—with the exception of the big landowners of the American South who from 1942 on were redirecting agricultural policies (Jamie Whitten). Before that date mixed farming was strongly encouraged (USDA Yearbook of Agriculture 1940). Melsted offered the farmer nothing with which to make a choice but locked him in the 'P,K,N cage'.

Now humus management was upheld by the Soil Conservation Service under Hugh Bennett. But when Bennett retired in 1951, a 'straw man' was appointed in his place, and attention was diverted away from humus management, etc. A 'flight forward' was chosen to defend the change: the fertiliser-fed crops would surely leave enough organic matter in the soil! Classical teaching on humus management got dubbed 'lamentations' by Joffe [94], and he wrote that it came from '*agronomists who then dominated the field of soil fertility. … A perusal of the writings of these specialists…. reveals the development of a soil organic matter mentality complex*'. In other words, Joffe and others who like him sounded the new agricultural policies simply denied the research of leading scientists in the field. When policy makers next lifted the unqualified adherence to the 'Liebig doctrines' to the status of 'civil obedience' (for advisors and researchers), the system got out of control for its lack of correction from the real world 'out there' that of ever-local farmers, plants, soils, and ecology. Post-war agronomy in countries like the USA, the UK, and the Netherlands was government-directed not just as to specific regulations but as to the very concepts and methods allowed (so lacking '*substantial rationality*' *sensu* Karl Mannheim). Mixed farming, the use of local resources, and a focus at a circular economy had been a characteristic of farming for centuries. They now were discarded, not because they had been disproved but because they stood in the way of the projected industrial fertiliser-only agriculture and its scale enlargement. Problems like soil deterioration and eutrophication of surface waters soon started to grow, but with historical agronomy discarded, there was little left to solve them. So it stands to reason that we open up history and look where we can find help. We return again to the mid-nineteenth century.

5. Focus at nutrient solubilisation

As indicated Liebig's influence was not absolute at mid-nineteenth century, not the least because researchers especially in France knew about the quality of De Saussure's experiments and explanations (Petit-Lafitte and de Gasparin were among them). And it was again the common experience with fertile soil from vegetable gardens that induced de Gasparin in 1852 to ask Verdeil and Risler a close investigation of water extracts from a number of such soils, after Liebig had stated that such soil extracts contained hardly any organics at all. Verdeil and Risler [95, 96] refuted that opinion. They showed that the extracts were indeed a source of N-compounds and demonstrated also that these extracts had very considerable mineral solubilising power. Their report was received favourably by the (French) Academy of Sciences [97]. And so the concept of soluble soil organics as central also to mineral nutrient mobilisation for plant uptake—expressed by earlier researchers—was fully corroborated. Risler continued with the research and published his results in the April 1858 issue of the *Archives des sciences de la Bibliothèque universelle* (Genève). He summarised [98] in 1872: **(1)** *this humus not only favours the solubilisation of certain mineral substances that are really needed for plants*, **(2)** *but it also furnishes plants part of their constituent carbon and facilitates the absorption of carbon from the atmosphere*.

The function of humus as a solubiliser and carrier of minerals—phosphate and potassium minerals among them—was implicit in the preparation of bone meal as phosphate fertiliser [99, 100]. Studied early in the century by Lampadius [101–105] and Sprengel, it was further developed by Grandeau ('matière noire') and others. Next in the mid-twentieth century, especially Chaminade [106–112] studied many aspects. Independently it was studied by Åslander, a Swedish researcher who focussed at phosphate fertilisation of the acid peat lands common at Northern latitudes [113–116]. Composted fertiliser with rather small amounts of phosphate sufficed, and no chalk was needed. And it was not fixed by the soil as 'super phosphate' was.

We saw already that the sweetish taste of the soil extract [52, 95–97] was connected with its mineral solubilising power: the solubilisation action of sugar-like compounds was investigated rather early [117]. The second half of the nineteenth century saw steady progress in the characterisation of carbohydrates, etc., but little of it was used by agricultural researchers. If we now jump to the post-Second World War decades, we find growing research in soil carbohydrates and related subjects as well as the changes in soil carbohydrates wrought by straw application but little attention to the interactions with minerals. But in the medical field, biotic (de)mineralisation came in focus early. A distinguished researcher was Carl Neuberg, a prominent biochemist who only recently received the attention he deserved [118]. Early in the twentieth century, he did research on glucuronic acids and related compounds as well as on mineral metabolism, and this starting position brought him ultimately to solubilisation and (de)mineralisation research. Neuberg was a refugee for the Nazi regime who only in 1941, at the age of 61, after great detours managed to reach the USA [119]. He then published a work on mineral solubilisation/(de)mineralisation, with *Remarkable properties of nucleic acids and nucleotides* [120] showing the solubilisation properties of these compounds. [121, 122] focussed at solubilisation and the Ca- and P-cycles in nature but were not noticed by agricultural research. [123, 124]'s work about *Solubilisation of insoluble matter in nature* gave rich (and startling) information but was again not noticed by agricultural research. [125] is a highly useful (last) review, [126] a moving series of lecture demonstrations; all was eminently useful for agricultural research and instruction, but none of it was noticed. *Agricultural research had become isolated*. It is only now catching up: as the reader will know recently humics as carrier of P-compounds became once more the subject of research.

6. Focus on mixotrophy and modelling

De Saussure [22] was well aware of the fact that humus was much too complex to allow component analysis. In 1917 Bottomley [127], by applying the same bicarbonate extractant that De Saussure had used but now without heating, got an extract in which he could show the presence of nucleic acid derivatives (see also [128]). In those decades the group of Schreiner at the USDA Bureau of Soils studied the role in soil-and-plant uptake of organic P-compounds [129, 130]. Schulow [131] and Weissflog and Mengdehl [132] managed to perform such uptake studies under strictly sterile circumstances and found that organic P uptake with maize compared well with uptake of inorganic P. Early on [77] there were already observations of phosphate dissolving power of plant roots; next also phosphate solubilisation by microorganisms was discovered, as was mycorrhizal P-compound uptake (easily disturbed by industrial fertiliser [133, 134]). Altogether we see a P-cycle with biota and organic interactions central and a broad scale of organic P-compounds contributing to plant nutrition. *There are a great number of 'actors' here that in a way are known to the local plant—primarily through its exudation and uptake of organic compounds. But the 'soil P tests' developed in the line of Liebig's 'elements as nutrients' approach offer us no entrance*. To understand that, we take a look at the Olsen available P test.

Olsen [135] has only a few references and misses out even on the most relevant American publications, not only on [136] but also on [137, 138] (refer to [132]). All were clearly expounding plant uptake and assimilation of organic phosphorus compounds. Olsen in fact disqualified his own test, for chemical researchers in the first post-war decades were obliged to consult the German and French literature. Yet, the test has been cited an unbelievable number of times and so helped to shape a virtual world of phosphate fertilisation that ultimately landed us in the extensive eutrophication that we now see everywhere. That Olsen's test is not about real soils is evident from [139–144]. But note that *early on such tests had been found invalid already at the highest soil scientific level* [145–149]. The post-war building was/is without foundations.

As to research on mixotrophy with N-compounds, the first specific investigations were with compounds known also from guano extracts. Wicke and his students perfected methods to study plant uptake of such compounds [150–153]. Uptake and assimilation of several compounds was proved, but with Wicke's successor focussing at animal nutrition, the organic uptake research was not continued. Yet we find uptake studies of organic compounds elsewhere; several reviews were published in the decades around 1900, and up till 1913 a number of PhD theses on the subject were published in Paris (some references in [87]). And at the end of the nineteenth century, the parlance equating 'elements' and 'nutrients' was found inadequate also by researchers who started their career under Liebig's influence. Leading plant physiologist Wilhelm Pfeffer in 1895 reintroduced the chemical concept in his *The election of organic nutrients [by plants]* and stressed that as a rule the plant will take up *organic compounds/complexes* of elements. Pfeffer focussed at lower plants, but his best student Czapek next took a close look at higher plants too. Research intensified, with much work done especially at the USDA Bureau of Soil by Oswald Schreiner's research group (see also [154]).

Czapek was by then the leading authority in the field and gave in 1920 two extensive overviews ([155, 156] fully acknowledging the work at the Bureau of Soils). When Pfeffer died Czapek was appointed in his chair (Leipzig), but Czapek himself died already in 1921, and in a bankrupt Germany there was little prospect for institutional continuity.

The war brought a rupture also in the work at the Bureau of Soils. Lathrop gave an extensive review of research with organic nitrogen compounds in soils and in plant nutrition [157], yet, in 1919, the same journal published Creighton's 'How the nitrogen problem has been solved' [158] that gave extensive accounts of nitrogen fixation industries without a word on soil-and-plant research. Moreover the nitrogen fixation unit that did research in nitrogen fixation for explosives production was positioned in the Bureau of Soils and dwarfed Schreiner's group (that now was obliged to focus far more on industrial fertilisers). Yet, Schreiner already in 1912 introduced an extended N-cycle [159, 160] pointing to thermodynamic a.o. advantages for the plant if it absorbs organic N breakdown products of soil organics before their 'mineralisation' (see also [161]). In the present this is a lively research subject, after researchers found organic N to contribute greatly to plant nutrition in boreal and arctic regions. In the soil there is a dazzling number of 'actors'—think also of biological nitrogen fixation—and of organic compounds that contribute to the soil-and-plant N-cycle. *Again it is the local plant that 'knows' about it all—and future models will have to start from that fact.* But neither the government nor the industry is at home in this soil world, and their orders—and fertiliser-centred models—are without power there.

7. Summary and outlook

There are many more important subjects waiting for exposition, from the high-level field experiments of Dehérain with their renewed attention to soils and organics and to the important and diverse roles of biochars in 'traditional' European agricultures. But the subjects touched upon will suffice to show that our post-war 'modern agriculture' was not for real. Its agronomy denied mixotrophy, organic solubilisation, and other organic-mineral interactions that, yet, had their roots in soil, farmer practices, and peer-reviewed science. Realising that much we are free again to effect a change to an agronomy for sustainable agricultures that starts from respecting both the soil and the work of those who interact with it daily. The suggestion that orders from the industry and government can make crops grow was at the centre of post-war policies. Its agronomy was ready-made for the purpose—think of its soil nutrient tests—but plants, earthworms, and microorganisms did not listen, and we ended up with global eutrophication and soil deterioration. Redevelopment is urgent and possible—not easy—and we are fortunate that there is a treasure of historical knowledge and experience that can assist us.

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