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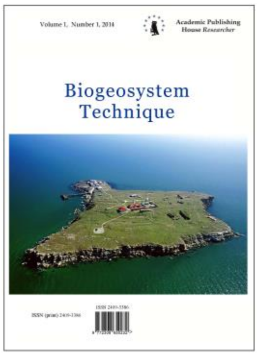

## Articles

# Is Inorganic Nitrogen the Normal Plant Fertilizer? Or Do Plants Grow Better on Organic Nitrogen? (Critical Review)

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## Abstract

Mineralized nutrients from artificial fertilizers, and from animal dung and plant residuals, are the cornerstone of modern conventional and organic agriculture. But they form a very risky strategy for fertilizing crops. Mineralized nitrogen is not the only way in which plants can get their nitrogen. In addition to the uptake of inorganic nitrogen, there are five other ways in which plants get their nitrogen. Inorganic nitrogen is not a safe way for plants to get their nitrogen. Ammonia, urea, and nitrate disturb the physiological processes in the plants, and, in consequence, the plants are an easy prey for pests and diseases. Ammonia and nitrate reduce the biodiversity in the patsures and the fields within a few years. But on the other side, not all the organic nitrogen is good for plants. When the symbiotic microbes are put aside by putrefactive microbes, the latter produce a lot of rotting compounds and toxins which hinder and even block the growth of the plants. The cations in conventional and biological products are not in balance, and many trace elelements are missing, with the result that not all nitrogen and sulphur are converted into real proteins. In the 19th and the beginning of the 20th century farmers developed systems to transform animal dung and plant residuals in a healthy plant food by mixing it with earth, heather sods or ditch dredge. By doing this, they kept the nutrients in the mixture and prevented the evaporation and washout of them into the air or the water (ground water). Other farmers added sea minerals to the farmyard manure and the compost. In this way, they gave the crops the necessary sodium, magnesium and trace elements. Crops fed with these products grow well. Still others used dung worms to convert animal dung and compost into valuable fertilizers for the soil and the plants. This vermicompost is a much better fertilizer than animal dung or warm compost. In organic agriculture, the yields are lagging behind because the plants can't get enough mineralized nitrogen and sulphur, and at the same time they are not able to get the organic nitrogen and sulphur compounds from the soil, because the symbiotic bacteria and fungi which can bring these organic nutrients directly into the plants, are not present, or blocked. The fertilizing systems in organic and conventional farming are

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based on the same system of mineralization before the uptake of the nutrients by the plants. For that reason, there are only minor differences in quality of the products from both systems. Inorganic nitrogen blocks the nitrogen fixation of leguminous and non leguminous plants, if the levels of it in the soil are too high. As they often are. Practical solutions were developed in the past by many farmers and some scientists. Most of them are forgotten, and must therefore be rediscovered. This article is part of a series in which I try to find out why the yields in organic farming are lagging behind in comparison to conventional farming, and why the quality of both product groups is comparable: not good enough. Lack of available (organic) nitrogen and sulphur seems to be the common key.

**Keywords:** inorganic nitrogen, sulphur, plant, fertilizer.

## 1. Introduction

Modern agriculture is based on seven pillars. The use of inorganic salts as plant feed is one of them. Ammonia and nitrate are the two salts, which farmers use to give as nitrogen fertilizers. And urea. Urea is broken down in ammonia and carbonic acid before the plants can use it. There are five other ways in which the plants can get nitrogen form the air or from the soil. With or without the help of symbionts. In all these cases, the plants take or get organic nitrogen.

The direct uptake of atmospheric nitrogen by the plants themselves is systematically overlooked by present-day agricultural science, although many scientists in the past have proven that plants can get nitrogen directly from the atmosphere. One of them found out with which organ plants assimilate atmospheric nitrogen directly without the help of symbionts.

Inorganic nitrogen salts disturb the physiological processes in plants, animals and men.

Very often the organically bound nitrogen in animal dung and warm compost in organic agriculture is not or not sufficiently available for the growing plants, although large amounts are given. During the stable time, the storage and the spreading of the dung, and during warm composting many nutrients are already lost. By adding earth, heather sods or ditch dredge to the farmyard dung and the compost these losses can be kept low. Artificial fertilizers also loose big amounts of nutrients into the environment.

Farmyard manure and warm compost contain many growth inhibiting substances which can be converted into good plant nutrients when these materials are given in the autumn. The conversion goes on during winter, but in the Netherlands the organic fertilizers are mostly given during the spring. So during the first weeks the growth of the young plants is inhibited. Farmers in the Netherlands are not allowed to spread organic fertilizers after the September begin.

Nitrogen fixation is disturbed when too large amounts of inorganic nitrogen is given. For nitrogen fixation, phosphor is the most important nutrient.

Inorganic nitrogen also lowers the amount of vitamin C in plants. Vitamin C is important for the natural resistance of plants against pests and diseases.

The differences in quality between organic and conventional agricultural products are small and often inconsistent: less nitrate and more magnesium and zinc in organic crops. In general, you can say that organic crops are, like conventional crops, also out of balance for its macro-elements. Besides, these products contain too much non-protein nitrogen, like ammonia, nitrate, and probably many other non-protein N compounds.

In three articles, I will investigate why artificial fertilizers and the organic fertilizers, as used today, are a risk for plants, animals and men. At the same time, this is a high risk for the environment and the biodiversity. Further, I will demonstate how farmers in the past were able to avoid these problems, and what we can learn from them.  I did not study he important question why modern agricultural science failed in solving these problems, although all the solutions were available in the older publications of the last two hunderds years.

### Six ways by which plants can get their nitrogen

### Inorganic nitrogen

In modern agriculture, the dominant view is that plants always get their nitrogen in an inorganic form – as ammonium or as nitrate. This is one of the cornerstones of the modern paradigm. Questioning this fundamentally means that an important building bloc of this paradigm is torn down. Other beliefs of the dominant paradigm are the overestimated role of potassium, the underestimation of the importance of carbon, sodium, silicon, magnesium, and trace elements. Another cornerstone is insufficient appreciation of the symbiotic relations between plants and microbes. Also the effects of all these on the health of plants, animals and men are systematically underestimated. Problems with pests and diseases, according to this paradigm, can be solved with pesticides and genetic engineering, and the hunger in the world can be solved with more and better artificial fertilizers and smart pesticides.

So inorganic nitrogen is one of seven pillars. In this article, this pillar is put under the magnifying glass.

Nitrogen.

In addition to ammonium and nitrate, there are at least five other ways by which plants can get their nitrogen.

These are the possibilities:

**Direct absorption of organic nitrogen**

Plants can absorb amino acids and proteins directly from the soil (Näsholm et al., 2000; Näsholm et al, 2009) or through the leaves (Krasil'nikov, 1958). There are plants that secrete proteases themselves. These are enzymes that break down proteins into peptides and amino acids, which are then directly absorbed by the plants through endocytose without first reducing them to ammonium or nitrate. And there are plants that even directly absorb the proteins as a whole (Paungfoo-Lonhienne et al., 2008).

**Endosymbionts**

Important groups of plants get amino acids from their rhizosphere symbionts, or from their above ground symbionts in leaves and stems:

- the rhizobia in the root nodules of the leguminosae. There is a very comprehensive literature about them. And recently scientists found bacteria which don't belong to the rhizobia but which are also able to form root nodules and assimilate nitrogen: in India it is proven that Caulobacter, a bacterium in the root nodules of Horse gram, also assimilates nitrogen. Just like the rhizobia, the Caulobacter belongs to the alpha proteobacteria (Edulamudi et al., 2011). Shiraishi and his colleagues discovered in 2010 that also Pseudomonas and Burkholderia form root nodules and assimilate nitrogen in the roots of Robinia Pseudoacacia (Shiraishi et al., 2010). They belong to the gamma and the beta proteobacteria respectively.
- Nitrogen assimilating cyanobacteria in special glands on the stems of the Gunneraceae (among which Giant rhubarb) (Santi et al., 2013). And Nostoc cyanobacteria in the leaf cavities of Azolla ferns in the wet rice cultivation;
- Frankia bacteria in the actinorhizia plant families – mostly trees and shrubs (Santi et al., 2013);
- The nitrogen fixing bacteria Azoarcus, Azospirillum en Herbaspirillum in the roots of grasses

and of rice. Although certain azospirillum groups also have positive effects on some wheat varieties, this is not a consequence of nitrogen assimilation but of other growth stimulating compounds from Azospirillum according to some authors (Clemente et al., 2016; Ribeiro et al, 2018). Karimi got higher wheat yields (plus 18 %) with azospirillum under drought stress. But this was, he said, a consequence of better root development through a higher indole acetic acid production by Azospirillum Zea Sp. 2. from wild wheat varieties (Karimi et al., 2018).

Lafferty Doty questions this:

"*In greenhouse studies with wheat, only inoculation with the wild-type strain of K. pneumoniae resulted in increased height and greenness under N-limited conditions compared to inoculation with a nif mutant or killed control strain, or uninoculated. These studies indicate that, while phytohormone modulation, vitamin synthesis, and increased mineral uptake and stress tolerance conferred by diazotrophic endophytes are important, N-fixation is also a key factor in the benefit of inoculation*" (Doty, 2017).

These four groups are so-called endosymbionts, because they offer their services in special organs or in the root surface of the plants with which they are connected. So they live inside the plants.

**Free living nitrogen fixers**

There are on the other hand free-living nitrogen fixers in the soil: Examples of these are azotobacter; actinomycetes, clostridium, azospirillum, klebsiella, burkholderia, and cyanobacteria. More and more species are being discovered that can bind atmospheric nitrogen. Many nitrogen-fixing bacteria belong to the proteobacteria.

**Symbionts, which release nitrogen from the soil humus or the soil particles**

Bacteria:

Then there are the symbionts, which do not assimilate nitrogen from the air themselves, but make the nitrogen free from the organic material, from the humic acids, or from the soil particles by consuming it. Humic acids can bind inorganic nitrogen. This group of symbionts includes bacteria, fungi and maybe also yeasts. These symbionts are then absorbed and "emptied by the plant roots", after which they go back into the soil and again collect nutrients over there (White et al., 2018).

White and his colleagues have demonstrated plausibly that plants, in order to obtain nitrogen, digest their soil symbionts by breaking down their cell membranes with aggressive oxygen compounds ($H_2O_2$). White speaks in this context of a rhizophagy cycle:

"*In the rhizophagy cycle, symbiotic microbes go from plants into the soil, acquire nutrients of various kinds, and carry nutrients back to plants, enter plant root cells where plants oxidatively extract nutrients from microbes, then plants deposit* [the] *microbes back into the soil from tips of root hairs to continue the* cycle "( White, 2019; see also White et al., 2018).

In his 2018 article, White published beautiful photos that give us an idea of these processes. The drivers are partly bacteria that release nitrogen from the organic material such as Micrococcus luteus and Bacillus amyloliquefaciens, and partly free-living nitrogen fixers such as Klebsiella and Burkholderia. It concerns **species-related symbionts**. Micrococcus luteus, for example, does stimulate tomatoes, but inhibits grasses and roots of other species.

This seems to be the most interesting group for our organic fertilizer discussion, just like the mycorrhizae, because they make the organically or minerally bound nitrogen also available for the plants. Without mineralization[*].

Mycorrhizae:

The mycorrhizal fungi. These fungi also release nitrogen and phosphorus from the soil and humus and transport it to the plant roots in the form of amino acids and organic phosphor. Nitrogen-binding bacteria are sometimes also found in special cavities (tubercles or nodules) of these fungi. Paul and his colleagues have demonstrated this for a pine species (*Pinus contorta*) that grows on poor soils (Paul et al., 2007).

Yeasts:

Yeasts can also bind nitrogen from the air and thus contribute to the better growth of crops. Sherry yeast is an absolute topper in this respect (Schanderl, 1947). In cereals (oats, wheat), sherry yeast strongly stimulated atmospheric nitrogen assimilation. It is not yet clear how it works. Are the yeasts doing the nitrogen fixation themselves and then 'eaten' by the plants (see White), or do they excrete their nitrogen in the rhizosphere zone after nitrogen fixation? Or do they produce stimulating compounds for the cereals which make the nitrogen fixation by the plants themselves possible? We do not know yet.

Schanderl demonstrated that specially selected wheat could extract up to 50 % of its nitrogen from the air by itself (Schanderl, 1947).

"*Mit Weizen habe ich folgendermassen experimentiert: 1939 habe ich auf einer der beiden hiesigen grossen Kaolinsandhalden 10.000 Weizenkörner ausgesät, von den Gedanken ausgehend, dass wohl 99 % der Pflanzen zugrunde gehen würden, dass aber diejenigen welche es sich unter den denkbar schwierigsten Bedingungen der N-Ernährung zu einer Körneransatz brächten, zur Luftstickstoffassimilation fähig sein müssten. In der tat sind von den*

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[*] Modern agriculture uses the word mineralization. By this they mean the freeing of inorganic elements and compounds from organic material and minerals: potassium from feldspath or biotite; phosphor from apatite; nitrate and ammonium, hydrogen sulphide, hydrogen cyanide and phosphine from organic materials or from the clayparticles. Minerals are however something completely different. Minerals are stones, inert materials which contain often silicates and aluminium plus metallic and non metallic elements. Nitrogen is not a part of these stoney materials. Nitrogen is in the air and in the organic compounds in the soil. Ammonium can be loosely bound to clay particles. Nitrate in the soil can bind with for example calcium. Together with calcium or as a salt ion, nitrate is lost very quickly to the groundwater or the drainwater. Nitrate can also bind to humic acids, but these are most of the time insufficiently present.
I have used the word mineralization in this text only because it has become the normal word for salts and salt ions. In fact we should call it salts and the proces salinization. Minerals normally are inert and stable. Easily soluble salts are agressive and lost easily.

*10.000 Pflanzen 9997 kläglich verhungert, nür 3 brachten es zu Ähren, und nur eine davon zu normaler Samenbildung. Mit Samen von dieser auf N-Anspruchslosigkeit selektionierten Pflanze wurde 1940 ein Gefässversuch mit Sand von 15 mg % N-Gehalt angesetzt und eine N-Bilanz aufgestellt. Das Wachstum dieser Selektions-Nachkommenschaft war für Weizen erstaunlich gut.* ***Die N Bilanz ergab dass der Weizen 50 % seines N-Bedarfes aus der Luft gedeckt haben musste*** *(..).*

*1942 würde je einem Gefäss eine zusätzliche Dünging von 25 mg N in Form von Hefe, und 140 mg N in Form von $KNO_3$ gegeben. Der N-Gewinn betrug im ersten Fall 170 mg, im zweiten Falle nur 53 mg"* (Schanderl, 1947: 173-174).

In his later trials in 1943, Schanderl found that some wheat grains were able – again – to collect 53 % of its nitrogen from the air (Schanderl, 1943). But, according to Schanderl, all wheat (and other crops with small seeds) need a sufficient nitrogen fertilization in the soil to start with, in order to get good N fixation rates from the air. And first you have to select those wheat grains which still have the faculty to fix nitrogen from the air. All hybrid wheat varieties can be excluded because Graem Sait[*] (Sait, 2018) has shown that these varieties are no longer able to take up kobalt. Kobalt is, like molybdenum, necessary for nitrogen fixation.

### Special nitrogen fixing hairs on the leaves

The plants can also assimilate themselves nitrogen through the special hairs on their leaves (Jamieson, 1910). Jamieson stated that his research has shown that all plants have such hairs. In his book of 1910, he first described why the observations and conclusions of Boussingault and Lawes that plants cannot absorb nitrogen ($N_2$) from the air were scientifically spoken untenable and that Ville with his trials was right. In 1853, Ville had proven that plants are able to absorb nitrogen from the air – nitrogen ($N_2$), not ammonia (Ville, 1853). Chevreul et al., appointed by the French government in a special committee, verified and confirmed it (Chevreul et al., 1855). But Ville didn't know which organ absorbed the nitrogen from the air. And the leading agricultural scientists of his time – Boussingault and Lawes – started their own trials, which 'proved that plants did not absorb nitrogen from the air'. So they rejected both the results of Ville and the confirmation by the Chevreul commission. But later on Atwater, Franck and Jamieson criticized strongly the trials of Boussingault and lawes as completely untenable (Jamieson, 1910).

Jamieson describes how he observed the plant Spergula[†] (*Spergula arvensis*) which is very rich in nitrogen, and noticed the numerous hairs on the leaves of this plant:

*"Rigorous microscopic examination, and careful and varied chemical tests, brought out that the hairs actually are absorbers of nitrogen from air, transformers of it into albumen, and conveyers of the albumen into the plant. What held good in Spergula would, it seemed likely, hold good in other plants; and actual examination showed that this was the case, i.e. that absorbers of nitrogen were found to occur, in one form or another, on all plants"*. (Jamieson, 1910: 101).

See for more detailed information on the research of Jamieson Appendix 1.

The interesting question then is why specialized symbionts are also needed as described above, if all plants have these nitrogen fixing hairs. Schanderl has proven that a double mechanism exists in leguminosae. He has demonstrated that leguminosae are perfectly able to fix nitrogen from the air without their root nodules (Schanderl, 1947). It looks like as if the root nodules produce extra nitrogen for the next generation, because Schanderl observed that these nodules break open and give their assimilated nitrogen to the soil, and not to the plants. Schanderl was also of the opinion that the root nodules offer the plants which with they are connected the special nitrogen fixation stimulating compounds and not nitrogen. "The nitrogen in the nodules comes from the leaves, not from the nodules". So just the other way round, according to Schanderl. Krasil'nikov agreed with this:

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[*] Graeme Sait: "The hybridized, green revolution grains, upon which most of our modern bread is based, attracted a Nobel prize for Norman Bourlag. (..)He did not use traditional hybridization techniques to create this more squat variety, which was much less prone to lodging. Instead, he irradiated the original wheat varieties and selected a mutant that became our main food. (..)There is one mineral that this compromised cereal can no longer uptake at all. This is the rarely-considered trace mineral, cobalt. (..) Cobalt is the building block for an incredibly important nutrient called vitamin B12. A key reason that many of us are now lacking this vitamin relates to the loss of cobalt in our most popular food" (Sait, 2018).

[†] In the past spargel was an important fodder crop in the Netherlands. Mostly as a stubble crop.

*"There are reasons to believe that root-nodule bacteria, as well as the bacteria from the nodules on the leaves of the above-mentioned plants, act favorably through their metabolites. According to our data, leguminous plants, in symbiosis with the nodule hacteria, fix molecular nitrogen for themselves from the air. The bacteria, due to their metabolic products, act as biocatalysts, activating the nitrogen-fixing ability"* (Krasil'nikov, Korenyako, 1946).

This is at least an interesting question: is the nitrogen from the leaves going down to the nodules, or from the nodules going up into the leaves? Let us look at it with an open mind. See the recent debate on the role of Azospirillum in wheat on page 4: Doty versus Karimi, Clemente, and Ribeiro. Maybe plant promoting compounds go – also – from the nodules to the leaves…

In my article about the work of Schanderl I have listed up all the pro's and contra's, and my conclusion is that Krasil'nikov and Schanderl were wrong on this point, but many arguments of

Schanderl regarding the root nodules and rhizobia are not yet answered. It is still urgent to answer them (Nigten, 2019b).

For cereals Jamieson observed that these 'grasses' have only small and few hairs for the collection and fixing of nitrogen from the air. Maybe for this reason you could think, grasses need special symbionts for nitrogen fixation: azoarcus; azospirillum etc (Paungfoo-Lonhienne et al., 2008). But the results of Schanderl (see above), Lipman and Taylor (1922) and of Rigg (1838) contradict this.

Probably the special hairs that Jamieson describes as nitrogen fixers are the filaments of the cyanobacterium in the plant cells. In free-living cyanobacteria, these filaments or hairs are called heterocysts. Air nitrogen is assimilated through these heterocysts. Heterocysts are extra protected against oxygen, because the splitting of the air nitrogen in an oxygen-rich environment is almost impossible (Figure 1). The cyanobacterium is one of the four primordial symbionts that together form the plant cells.

This would then be the same ancient symbiont that also takes care of photosynthesis in the leaves, (in) the chlorofyll granules, descendants of a cyanobacterium (Nigten, 2020). The other main symbionts of the plant cell are adapted forms of proteobacteria (the mitochondrium), of spirochetes (for the transport and cell division system (mitosis)), and the mother cell in which all symbionts are included (an archaea, probably Thermoplasma acidophilum[*]) (Margulis, Schwartz, 1988; Margulis et al., 2009). In addition, more and more "specialised" symbionts are being discovered.

This concerns both fungi, bacteria and beneficial viruses (Béchamp, 1883; Pradeu et al., 2016).The research into viruslike structures in bacteria and their roles points out that these semi-organelles fullfill important roles as symbionts in the bacteria:

"*The number of bacteria that are found to depend on phages for crucial functions increases almost by the day*" (..) *"It seems that some phages[†] have become almost permanent components of bacteria"* (Hunter, 2008).

**All the above described routes provide organically bound nitrogen**.

In a similar way, organically bound other elements such as phosphorus, potassium, calcium and magnesium are also supplied by soil life (Krasil'nikov, 1958). Iron, for example, is bound by siderophores[‡] and transported into the cells. Zinc is said to use quercetin as the ionophore[§]. Many ionophores are produced by microbes, some by the plants themselves. Phosphorus is also released from the soil particles by the mycorrhizal fungi and delivered (organically bound) to the plant roots.

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[*] Yutin et al abnegate the theory of Margulis regarding Thermoplasma acidophylum as the primal cell of the eukaryotes.
They think , based on phylogenetic analysis, that an extinct archaea is the one (Yutin et al., 2008).

[†] Phages are bacteriophages, literally bacteria eating viruses.

[‡] *"Siderophores (Greek: "iron carrier") are small, high-affinity iron-chelating compounds that are secreted by microorganisms such as bacteria and fungi and serve primarily to transport iron across cell membranes, although a widening range of siderophore functions is now being appreciated. Siderophores are among the strongest soluble $Fe^{3+}$ binding agents known"*. Source Wikipedia english: siderophore.

[§] For more information on ionophores – ion carriers (see Wikipedia english: ionophore).

**Fig. 1.** Heterocysts. With the cyanobacterium (left under);
only the heterocyst in the hairs (right, see the arrow)

**The crux of the problem.**

• Nitrate and ammonia ... disturbing nutrients.

As early as 1912, Schreiner plausibly argued that nitrate and ammonium are not the preferable nitrogen sources. For example, he clarified for nitrate that the plants must first extract the oxygen from the nitrate – $NO_3$. That takes a lot of energy. And then, the entire formation of amino acids still has to take place before the built up of proteins can start (Schreiner, Skinner, 1912a). This is all very inefficient. Visser goes a step further in his thesis from 2010 and basing on the extensive literature research concludes that nitrate and ammonium are actually the most harmful nitrogen forms for the plants (Visser, 2010). The plants are overfed with it, and the carbon is missing in both ammonium and nitrate. According to Jones, this leads to an exhaustion of soil carbon, and through this, the soil life is declining (Jones, 2015).

Due to these phenomena, in combination with a lack of magnesium and trace elements, the plants cannot convert all the inorganic nitrogen absorbed into complete proteins, which weakens its resistance (Anjana and Umar, 2018). The plant becomes an easy prey for diseases and pests (Hornick, 1994; Visser, 2010). Microbes, nematodes and insects love nitrate, ammonium, ureum, nitric oxide, nitrosamines and even whole amino acids in the plant, but not proteins. They can't eat the proteins in the plants (Chaboussou, 2005).

Not only nitrate can disturb physiological processes in plants but also ammonium. Britto and Kronzucker have given an overview in 2002 (Britto, Kronzucker, 2002).

The most interesting of their findings are these:

- Charles Darwin already in 1882 saw growth inhibition in euphorbia peplus through ammonium. (In the same period, Julius Hensel condemned the use of farmyard manure, because he thought the ammonia in it was harmful for the crops. Instead of that, he stimulated the use of rock flour as a fertilizer).
- In humans ammonium can cause neurological and insulin disorders. And: *"Sensitivity to $NH_4^+$ may be a universal biological phenomenon, as it has also been observed in many animal systems"*.
- In the majority of ecological systems, the values of $NH_4^+$ in the soil solution vary between 0.4 mmol/l and 4 mmol/l. In agricultural soils, it often ranges from 2 to 20 mmol/l.
- The large amounts of human-made ammonium in ecosystems affect not only individual species but also e.g. the decline of forests;
- The threshold at which ammonium becomes harmful differs per plant species. Britto gives some examples of sensitive plants, among which tomatoes and potatoes. Other plants like rice, onions and leeks are highly adapted to ammonium. But these plants can also suffer from

ammonium toxicity if the amount given is too high. When also nitrate and potassium were given this ammonium toxicity became less;

- Symptoms of ammonium toxicity in the sensitive species appear mostly at $NH_4^+$ in the soil solution above 0.1 to 0.5 mmol/l. Some symptoms are: lower seed germination, and less seedling establishment; chlorosis in the leaves; diminished growth; a possible (still much discussed) intracellular disturbed pH; lower yields and even plant death;
- *"Symptoms not so readily visible, but equally important, can include a decline in mycorrhizal associations".*
- Less potassium, magnesium and calcium, and more phosphate, sulphate and chloride in the plant tissues through ammonium. Some acids like malate acid go also down, while amino acid concentration increase; rhizosphere acidifies after ammonium uptake, while alkalizing happens after uptake of nitrate. So most plants which tolerate ammonium are also acid tolerant.
- The way in which ammonium enters the root cells is still highly debated. One of the ideas is that there is a lack of regulation for the uptake of ammonium. Maybe because the potassium channels for the uptake of potassium are also used for the uptake of ammonium;
- The content of sugar and starch in plants decreases with ammonium fertilization. This can be induced through damage of the photosynthetic centers. A possible side effect is less ascorbate because of less carbon. Ascorbate is the anion of vitamin C.
- Ammonium inhibits the uptake of nitrate to a certain degree. But extra nitrate can alleviate ammonium toxicity in ammonium sensitive plants;

In later research, Balkos and Britto found out that for rice it helps to give extra potassium to mitigate the harmful effects of ammonium. Rice is a non-sensitive species (Balkos, Britto, 2010).

More interesting is what Britto and his colleagues did not investigate. Eight questions:

- Are there no alternatives for ammonium and nitrate like organic nitrogen compounds?
- Which other elements are necessary for mitigating the harmful effects of ammonium (and nitrate)? Potassium plays only a minor role in the conversion of ammonia and nitrate into real proteins.
- Why is the general level for harmless ammonium – under 0.1 to 0.5 mmol/l for sensitive species – so low? What is the level of ammonium in the top layer of the soil if you spread for instance 100 kg $NH_{4+}$ N/ha as ammonium fertilizer? And what if you do this ten years or more in a row?
- And what is the general level for the amount of harmless ammonium for non-sensitive species? And for soil life? The results of the Bernburg trials (1910-1962) gives detailed information for differences in bacterial numbers depending on different treatments*. See Appendix 2.
- In which way is ammonium in natural ecosystems bound in the soils (clay particles; humic acids; fulvic acids; other organic matter)? And is there a maximum level for binding ammonium in different soils? Or, in other words, at what level is ammonium lost from soils? Or is it always lost to some degree?
- What are the consequences for human and animal health if crops contain ammonium in their tissues? And is there a safe level?
- Why do you have to spread say 100 kg/ha of ammonium fertilizers to get 40 % in the crops? Is here a physiological mechanism at work? And which? Osmosis?
- Does ammonium (and nitrate) also lower the content of other vitamins than vitamin C?

In a recent study, a negative impact of inorganic fertilizers on the rhizosphere microbiome of wheat plants is proven (Reid et al., 2021):

*"The profound negative effect of inorganic chemical fertilizer application on rhizobacterial diversity has been well documented using 16S rRNA gene amplicon sequencing and predictive*

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* From the trials at the Bernburg experimental station (1910-1962) in Germany we know that the highest bacterial count was found in the fields which were treated with animal dung. 33.86 million bacteria in one gram soil. In the treatment with only nitrogen the count was 11.2 million bacteria. The animal dung parcell had almost the highest nitrogen percentage. The highest was the parcel treated with animal dung plus phosphor and potassium, but no extra nitrogen. In the parcel treated with NPK (N= nitrate) the soil nitrogen was low. Even less than the control: 0,038 against 0,066. And the bacterial count was also low (Poschenrieder and Lesch, 1942). See Appendix 2 for the exact data of all treatments and an interesting ascertainment: the nitrogen of farmyard manure is in the soil, but nevertheless insufficiently available for the plants.

*metagenomics. (..).In general, fertilizer addition decreased the proportion of nutrient-solubilizing bacteria (nitrate, phosphate, potassium, iron, and zinc) isolated from rhizocompartments in wheat whereas salt tolerant bacteria were not affected (..). We hypothesized that the addition of chemical fertilizer would reduce putative Plant Growth-Promoting Rhizobacteria populations in wheat. We found that the abundance of rhizobacteria with acquisitional traits for key plant nutrients (endogenous nitrogen, phosphate, potassium, iron, and zinc mobilization) were significantly reduced in wheat grown in soils treated with NPK fertilizer.*

*This study contributes to our understanding of the impact of fertilizer on wheat rhizobacteria and supports previous studies showing the deleterious effect of chemical fertilizer on plant rhizobacteria, particularly through highlighting the greater abundance of putative Plant Growth-Promoting Rhizobacteria in unfertilized plants. It is assumed that wild relatives have co-evolved with the microbial community of native soils, selecting microbes beneficial to growth and health. Here, we show the probability that wheat plants can select growth-promoting bacteria to their roots to establish mutually beneficial associations and that chemical fertilizer reduces this selection"* (Reid et al., 2021).

But 'there is still uncertainty about the exact mechanisms how or why this is caused'. The authors developed a hypothesis about competition between rhizosphere bacteria and non symbiotic bacteria:

*"However, it is unclear why fertilizer addition would inhibit root colonization by these bacteria. It is possible that rhizobacteria are less able to metabolize primary nutrients in the form presented in agricultural fertilizers than other members of the soil microbiome. If this is the case, it would follow that they are also less competitive in this environment and this would be reflected in their lower abundance"* (Reid et al., 2021).

Future research.

In future research, the methods developed by Reid et al. can be used to check if the rhizosphere bacteria in current organic agriculture are repressed in a comparable way by farmyard manure, slurry or heated composts as in inorganic fertilizing. And at what levels inorganic fertilizers repress the rhizosphere biome? And what is the influence of toxic organic nitrogen compounds on the rhizosphere biome? Are the effects of the toxic organic nitrogen and sulphur compounds in rotting farmyard manure, slurry or in warm compost on the rhizosphere biome comparable to the effect of inorganic fertilizers of which Reid et al. talk?

Organic nitrogen in farmyard manure: present but not available … a complicated problem.

The crux of the problem of farmyard manure seems to be that on the one hand, there is mostly sufficient organic nitrogen in the soil, but on the other hand, at the same time it is not available or at least not sufficiently accessible for the crops.

Lawes and Gilbert (1858) confirmed this in their report about the results of a three years trial on meadowland with 17 treatments, among which a treatment with pure minerals (K + Na + P + Ca + S + Mg; and no ammonium, nor nitrate); a treatment with ammoniacal salts; a treatment with farmyard manure; one with farmyard manure plus ammoniacal salts; one with minerals salts, ammoniacal salts and cut wheat straw and one with farmyard manure plus 200 lbs ammoniacal salts.

Lawes noticed that the pure mineral treatment had very positive effects on the leguminous herbage, and that the pure ammoniacal salts had only positive effects on the gramineous plants. And that farmyard manure in this respect had an in between position:

*"That the mineral constituents of the dung had their share of effect, would appear from the fact, that the Leguminous herbage was moderately luxuriant on the dung plot, and that those of the Grasses were the most developed which were increased in their proportion to the rest by the artificial mineral manures. And again, that the nitrogen also of the dung was effective, may be judged, not only from the general development of the Graminaceous*

*plants under its use, but from the fact of a like fullness in the proportion of the Grasses in flowering and seeding stem, as where ammoniacal salts were employed in conjunction with the mixed mineral manure.*

*It would appear, however, that a much less proportion of the whole nitrogen supplied to the land was active, when it was provided in the form of farmyard manure, than when in that of ammoniacal salts. There would, in fact, be considerably more of nitrogen applied per acre in the 14 tons of farmyard manure, than in the 400 lbs. of the mixed ammoniacal salts. Nevertheless, the encouragement of the Leguminous plants was much greater, and that of the Graminaceous* *ones much less, where the farmyard manure was employed, than where the 400 lbs of ammoniacal salts, together with the mixed mineral manure, were used.*

*That the less produce by the farmyard manure, than by the mixed mineral manure and 400 lbs. of ammoniacal salts, was due to a deficiency of available nitrogen, notwithstanding the large actual amount of it in the dung, would appear from the fact, that on the employment of 200 lbs. of ammoniacal salts in addition to the farmyard manure (Plot 17), there was a further average annual increase of 8 3/8 cwts, of hay per acre. Still, even with this addition, there was about ½ a ton less of hay annually than where the " mixed mineral manure" and the "400 lbs. of ammoniacal salts" were applied.*

*The evidence regarding the action of the farmyard manure goes to show, that, though it is doubtless a very complete and important restorer of both the mineral constituents and the nitrogen required to repair the exhaustion of this most greedy crop, yet, the amount of these constituents supplied by its means is proportionally much less active within a given time than that provided in the artificial combinations"* (Lawes, Gilbert, 1858: 568).

Results of the three years trial on meadowland of Lawes and Gilbert are presented in the Table 1.

**Table 1.** Treatments with different fertilizers (from Lawes, Gilbert, 1858: 558)

| Manures per acre per annum | Average yield of three years, t | Average annual increase by manure | Striking effect |
|---|---|---|---|
| T 1. Unmanured | 1.203 ton | - | Grasses and legumes |
| T 4: 200 lbs ammonia sulphate and 200 Lbs ammonia murate | 1.762 ton | Plus 0.559 ton. | Grasses, almost no legumes |
| T 8 Mixed mineral manure: K + Na + P + Ca + S + Mg | 1.66 ton 13 cwt | Plus 0.457 ton | Legumes, almost no grasses |
| T 10 Mixed mineral manure and 200 lbs ammonia sulphate and 200 Lbs ammonia murate | 2.965 ton | 1.762 ton | |
| T 12. Mixed mineral manure; 200 lbs ammonia sulphate and 200 Lbs ammonia murate, and 2000 lbs cut wheat straw | 2.711 ton | 1.508 ton | Five cwt less than T 10 through the wheat straw |
| T 16. 14 ton Farmyard manure | 2 ton | 0.813 ton | Grasses, and some legumes. |
| T 17. 14 ton Farmyard manure plus 100 lbs ammonia sulphate and 100 Lbs ammonia murate | 2.406 ton | 1.203 ton | |

Here we see that 14 ton farmyard manure – T16 – has a lower yield than T10 – artificial ammonia fertilizers plus mixed mineral manure K + Na + P + Ca + S + Mg, although according to Lawes the 14 ton farmyard manure contains much more nitrogen than the artificial ammonia fertilizers in T10[*].

But couldn't plants directly absorb amino acids or proteins as stated above? Yes, but then the organic nitrogen compounds must be amino acids or proteins for most of these plants, and they must be accessible to the plant roots. It seems that the absorption of organic nitrogen for roughly 85-90 % of the plants requires the mediation of the microorganisms in the soil – the symbionts: mycorrhizae or bacteria. But then there must be symbionts available. And also the right symbionts.

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[*] In the Netherlands farmyard manure contains roughly 5% $N_{tot}$ in fresh product (Blgg AgroXpertus, 2011). So in 14 ton FYM there is roughly 700 kg $N_{tot}$. Indeed, much more than in 400 pounds of the ammonia fertilizers.

The research by Paungfoo-Lonhienne (Paungfoo-Lonhienne et al., 2008) showed that a member of the *brassicaceae* family – the sand rocket – was able to absorb proteins directly, without the intervention of microorganisms. The plants examined secrete proteases themselves that break down proteins into amino acids that they can absorb via endocytosis. The *Brassicaceae* don't have mycorrhizal fungi as symbionts. And they don't need them. They are able to process proteins by themselves.

*"Digestion and uptake of protein may be widespread in the plant kingdom and may be crucially important for the 10 % of plant species that do not form mycorrhizal symbioses* (Paungfoo-Lonhienne et al., 2008: 4527).

**And why do the plants in agriculture, based on farmyard manure or slurry not use their special hairs to fix nitrogen from the air?**

There are different reasons why this does not happen, or not as much as necessary or possible:

1. Growth inhibitors and toxins from deep litter manure, slurry*, warm compost and their putrefactive bacteria suppress and hinder the plant growth and the symbiotic microbes around the roots. So the plants can't get enough organic nitrogen from the soil to start their growing. First they have to build their young green leaves before the nitrogen fixation in the hairs of their green leaves can begin (Schanderl, 1947);
2. When there is too much nitrate or ammonia in the soil, nitrogen fixation on the leaves stops. On most organic farms, nitrate and ammonia are the only nitrogen compounds available for the plants in the beginning of the growth season, because the organic nitrogen is not accessible (see point 1);
3. All the trace elements necessary for nitrogen fixation should be available. So at least kobalt, molybdenum, zinc and magnesium must be there in sufficient amounts. And probably much more trace elements. In many soils these trace elements are low, missing or not available (Dimkpa, Bindrapan, 2016). And ammonia plus potassium hinder the uptake of many cations, including trace elements;
4. And growth stimulators like auxins, cytokinins and gibberellins support these processes. So they should be available too. For their production symbiotic microbes around the roots are unmissable;
5. Pesticides may disturb the work of the symbionts, and the cooperation between plants and their symbionts. In a recent study in the Netherlands, it became clear that also in organic agriculture there are many different residuals of pesticides (Buijs, Samwel Mantingh, 2019). Partly, they come from outside organic agriculture and partly form the dairy farms themselves. From the past or from actual use. Organic dairies use insecticides and vermicides against flies on, and worms inside the cows. And this is still officially permitted.

**What can we learn from the literature about nitrogen availability from farmyard manure, slurry and warm compost in (organic) agriculture?**

The farmyard manure, slurry and plant residuals must first be pre-digested by non-symbiotic microbes before the symbionts can start working. Cellulose, hemicellulose and lignin have to be broken down before the cell cytoplasm can be digested. This pre-digestion takes time (Rusch, 1968; Krasil'nikov, 1958). But because the manures in the Netherlands are often applied in the spring, that necessary time is missing. The digestion, which follows then, often also produces substances that temporarily inhibit the growth of the plants. This is partly because the quality of the manure or the compost itself leaves much to be desired. It contains, as you can smell, too much non-protein nitrogen, and non-protein sulphur, NPN and NPS. And the very toxic phosphine, $PH_3$ and Hydrocyanic acid, HCN. Such manures and compost often stimulate the wrong bacteria – decay bacteria. These putrefactive bacteria produce toxins, such as mercaptans, putrescins, cadaverins, indoles, and skatoles (Hennig, 1996) and eventually these substances are converted into ammonia, hydrogen sulfide, hydrogen cyanide, nitrous oxide (Laughing gas), nitrate, phosphine and gaseous nitrogen ($N_2$) in the manure, which emit easily. Especially phosphine emits very quickly from the manure heaps and the slurry pits, because it is poorly soluble in water. In the modern emission literature it is never mentioned, but in the 19th century it was already memorized (Bowditch, 1856).

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[*] Not all slurry is giving rotting. We have shown that a slurry with a C/N ratio of twelve and up gives little rotting compounds like ammonia (Vanhoof, Nigten, 2020).

Losses of inorganic nitrogen – and other anions – in historical perspective:

Bowditch, a reverent of St Andrews at Wakefield, studied the losses of nitrogen, sulphur and phosphor from manure heaps, from stored blood from slaughterhouses and other slaughter residuals, and from heaps with vegetable residuals. He showed how much ammonia, hydrogen sulphide and phosphine was lost from these residuals. His purpose was to demonstrate the farmers and workers the losses from these heaps, not with laboratory results but with the smells which escaped from these residuals and with test paper which coloured blue if there was emitted ammonia, hydrogen sulphide or phosphine.

And also he made clear to the farmers how they could keep these valuable elements in the heaps by mixing earth with the residuals, often in a ratio of one to one. Then the heaps gave no more smells at all. And the end product gave very good yields as he demonstrated. He also argued that much phosphor was lost from the heaps by the evaporation of phosphine. Phosphine he said, is not as good dissolved in water, as ammonia and hydrogen sulphide. In fact, he showed, it escapes from the first moment it arises.

"*The former gas [hydrogen sulphide] is therefore twenty four times more soluble than the latter [phosphine]*" (Bowditch, 1856).

And he stated it is the oxide of iron and of alumina and silica of the earth which binds these precious elements. For this he refers to the experiments of Way and Thompson, and to Liebig. He pointed especially to the role of hydrogen ions which catch nitrogen, sulphur, carbon and phospor in a very agressive way, before emitting. He didn't make clear where the hydrogen comes from. I think he supposes it comes from the degradation of proteins.

The main mistake, he says, which is made is that men wants to see quick results, for instance by heating the compost heaps, but nature never works quickly. Processes in nature are always slow. So we should also work slow. Only then we can keep the valuable elements in the residual heaps. Earth, he argues, helps us to work slowly. And he reminds us that the normal treatment of manure heaps and compost heaps by the farmers is such that the precious elements are lost, and in spring these farmers buy the same lost materials from the fertilizer industry:

*"What renders the case more noticeable, is, that the burning is the worst*[*] *when the evaporation is the greatest, and no spectacle is more familiar to an observer of the fermentation of manure than a cloud of white vapour which completely conceals the workmen who are removing a heap of "firefanged"* [†] *horse dung.*

*But every particle of that exhaling moisture was designed by a beneficent Providence to be condensed into a liquid charged with the precious burden which it is now bearing away on the wings of the wind. Elements of corn and cattle are volatilizing with every grain of the steam, and (in towns) are becoming sources of disease and death*[‡] *to those whom, if differently managed, they might feed! And why? Simply because man will defeat nature.*

*Nature designed putrefaction (combustion) to be slow, and to that end required all decomposing refuse to be buried, in which case its slow but useful conversion was certain. Man on the other hand places the waste substances so that the combustion may be rapid. He employs the light porous material straw to mix with animal excreta, and places the whole so as to ensure a free passage of oxygen among the putrefying mass" (..).* [Through the heating the water in the heaps evaporates…]

*"But suppose all the water had been retained by the heap. Suppose the oxygen had been supplied to the decaying mass as it is supplied in the soil, abundantly but yet slowly, would there have been any firefang, or would the ammonia and other valuable products have flown away almost as quickly as they were generated? We are always wrong when we can perceive a law of nature and do not conform to it*" (Bowditch, 1856: 328).

But not only from farmyard manure and warm compost a lot of nutrients are lost. The same is true for articial fertilizers.

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[*] Here Bowditch means, 'that the burning is the strongest..'

[†] Firefang is, I think, something like a smoldering fire. In the modern dictionaries, I couldn't find a translation of firefang.

[‡] Bowditch gave in his tekst an example of his son who got 'typhus' when he got too much of this smelly odors from a manure heap.

In 1856 lawes and Gilbert, two english scientists, published the results of their research into the partial utilization of nitrogen:

*"As a final average it is seen that we have, including all these cases and extending over so many years, in the case of wheat, only 39.9 per cent., and in that of barley only 43.1 per cent, of the nitrogen of the manure recovered in the increase of crop ! (..) So much, then, for the indications of some hundreds of direct experiments on this subject. But we further unhesitatingly maintain, that the general result here arrived at, agrees very closely indeed with that of common experience in the use of guano and other nitrogenous manures for the increased growth of grain"* (Lawes, Gilbert, 1856: 484-485).

In 2017, Yuan and Peng came to similar conclusions for China (Yuan and Peng, 2017): In 1961, when nitrogen fixation and animal dung were the most important sources of nitrogen in China, 59.4 % of all the nitrogen which was brougth to the land was utilized by the crops. In 2012, when artificial fertilizer was the main nitrogen source only 37.5 % was utilized by the crops. The remaining 62.5 % goes in the environment, resulting in dead zones in lakes and seas, in the disappearance of rare plant and animal species in nature and in the pastures and fields, and in pollution of drinking water.

The biggest part of the 37.5 % nitrogen which is taken up by the crops also ends in the environment after being eaten by men and animals, from the slurry pit, the deep litter stables, the compost heaps, slaughter residuals, and the sewage treatments. All three are ideal places for emissions. So roughly about 90 % of the nitrogen fertilizers is lost in one cycle. Jones also comes up with losses of 60-90 % (Jones, 2015).

And the losses from farmyard manure at Rothamsted are even higher:

*"The measurements and calculations in these tests are all so simple in kind that they can hardly be distrusted or devalued. They are simply matters of sampling and analysis and multiplication by the total weights involved. The nitrogen content of the top nine inches of soil has been considered. Figures given are those for an acre. On one plot the only manuring was with farmyard manure each year. This gave to the soil 201 pounds of nitrogen per year. To this supply must be added 7 pounds to cover the rainfall contribution and the nitrogen in the seed sown. So, each year, the soil totally received 208 pounds of nitrogen. But each wheat crop removed 50 pounds of nitrogen per year. So the soil should have gained 158 pounds annually.*

*In 1865 the total nitrogen content in the soil per acre was 4,850 pounds; and, by 1914, it was 5,590 pounds. A gain in forty-nine years of 740 pounds, which works out at only just about 15 pounds per year. The theoretical annual gain of 158 pounds is reduced in fact to a mere 15—so there was, therefore, an average loss of 143 pounds of nitrogen per year"*. (Hopkins, 1956).

That is a yearly loss of 71 %. Even more than from artificial N fertilizers during cropping.

The positive effect of farmyard manure for carbon sequestration in the soil is another question. Although lots of carbon (and nitrogen) are lost in the stable or during composting and in the field the net result for fertilizing with farmyard manure is that the organic matter in the soil stays on level and the same applies for nitrogen during a fifty years trial:

*"At Woburn, continuous cereal cropping from 1876 to 1926 showed a 33 per cent loss in organic matter content where only fertilizers had been used—but little loss where large applications of farmyard manure had been regularly given. This comparison was worked out from the figures for carbon content and nitrogen content in 1876 and in 1926, it being assumed that the organic matter content was fairly proportional to these figures. These were the figures"* (Hopkins, 1956) (Table 2).

**Table 2.** Carbon and Nitrogen content in the soil under different fertilizing schemes

| Fertilizer | Carbon content percentage | | Nitrogen content percentage | |
|---|---|---|---|---|
| | 1876 | 1926 | 1876 | 1926 |
| Manured* plot | 1.48 | 1.5 | 0.155 | 0.15 |
| NPK plot | 1.48 | 1.0 | 0.155 | 0.09 |

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* Manured with farmyard manure.

As Hopkins remarks, in both ways of fertilizing the C/N ratio stays 10 : 1, but the artificial fertilizers give a reduction of carbon ánd nitrogen. The yields, and the total amounts lost are something completely different. (See also Appendix 2 for the nitrogen content in the soil from farmyard manure).

So in 160 years we can say there is no improvement as far as effective use of nitrogen is concerned. And the losses of carbon, potassium, phosphor and sulphur into the air and soil are not even mentioned in many government proposals. Phosphor into the groundwater is the exception.

At the moment, in the Netherlands the goverment has reduced the whole question of losses from the manure into losses of ammonia as far as agriculture is concerned. The measurements of my colleague showed that also hydrocyanic acid (HCN) evaporates from the slurry. And of course there is the loss of laughing gas, $NO_{x,}$ and $N_2$. And are there other volatile nitrogen compounds, which we miss while measuring because our equipment can't measure them? Casey sums up many of these compounds (Casey et al., 2006). And sometimes you get the feeling that science and the goverment don't want to measure them at all, because more lost nitrogen means more political problems.

And the losses from the great compost factories, from the sewage treatments or from the processing of cadavers and slaughterhouse residuals are not even mentioned.

According to Hao (Hao and Benke, 2008), from 13 % up to 70 % of the total nitrogen from the beginning of the composting proces can be lost as ammonia. Other losses are laughing gas, nitrate and inert nitrogen ($N_2$). Hao proposes many interesting methods to diminish these losses:

- Extra straw or woodchip for increasing the C:N ratio;
- Less turnings and smaller heaps;
- Acidification by adding phosphoric acid, $MgCl_2$ or $Al_2(SO_4)_3$; S;
- Binding ammonia with coir, zeolite or peat;
- And the adding of magnesium and phosphor salts for forming Struvite.

Many of these proposals were already made in the 19th century. But then the conclusion was that the simplest, cheapest and best way was adding earth.

And as we know now this old method can be combined with worms to make vermicompost. Pfeiffer saw thousands of worms in these with earth enriched heaps. He didn't even have to add them (Pfeiffer, 1936).

- **Growth inhibiting substances.**

In the period 1905–1915, Schreiner[*] and his colleagues drew up a list of about 20 growth inhibiting substances that are released from the organic conversion or decay processes in the soil. Schreiner suspected that this was due to too little oxygen in the top layer. He identified important growth inhibition through the following substances: dihydroxystearic acid; aldehydes; guanidine; coumarin etc. Dihydroxystearic acid could be detected in all soils with sufficient nutrients yet with poor growth. Laboratory tests confirmed the growth-inhibiting properties of this acid. Guanidine is especially interesting as it is part of urine[†]. The experiments of Schreiner demonstrated that guanidine inhibits the uptake of nitrate, potassium and phosphor:

*"The total phosphate, nitrate, and potash removed by the normal plants was I,608.9 milligrams, against only 1,088.5 milligrams in the guanidin set. The phosphate removed was 427.3 milligrams in the control and 287.0 milligrams in the guanidin set; the potash was 723.7 milligrams for the control and 496.7 milligrams for the guanidin set; the nitrate was 457.9 milligrams for the control cultures and 304.8 milligrams for the guanidin cultures" (..)*

*"Guanidin, as carbonate, is shown to be harmful to wheat, corn, cowpeas, and potato plants. It produces an effect similar to a physiological disease. The plant is normal for a few days, then begins to show a spotted appearance on leaf and stem. This effect develops until the plant is*

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[*] In addition to research into growth-inhibiting substances, Schreiner has also extensively researched which organic nitrogen compounds promote growth. For example, he and his colleagues have extensively tested the following growth-promoting substances: histidine, creatinine and arginine, as well as hypoxanthine, xantine and the nucleic acids. I have written a separate article about the work of Schreiner and his colleagues. In Dutch (Nigten, 2019).

[†] In Wikipedia we find: "*Guanidine is the compound with the formula $HNC(NH_2)_2$ It is a colourless solid that dissolves in polar solvents. It is a strong base that is used in the production of plastics and explosives. It is found in urine as a normal product of protein metabolism"* Source: wikipedia english: keyword: guanidine.

*bleached to a considerable extent, with final collapse. This harmful effect of guanidin on plants is augmented by the presence of nitrate and increases with the amount of nitrate present"*. (Schreiner, Skinner, 1912b).

Especially in combination with nitrate, guanidine was thus very harmful for the wheat plants in this trial. When nitrogen was given as asparagin or creatinin the harmful effects of guanidine did not occur.

Forty years later McCalla and his colleagues continued the work of Schreiner et al. They came to similar conclusions:

*"Soil microorganisms produce a tremendous variety of organic substances during the decomposition of plant and animal residues, and, as numerous studies have shown, some of these substances are phytotoxic. For example, Swaby found that, when soil micro-organisms were present in association with plant residues (lucerne and Phalaris tuberosa), substances inhibitory to plant growth were frequently produced"* (McCalla, Haskins, 1964: 192).

And they validated also the conclusions of Schreiner regarding growth stimulating organic compounds:

*"(..)Although green plants can live autotrophically, it is apparent that under suitable conditions they can also live heterotrophically, absorbing organic compounds from their surroundings and metabolizing these compounds. Plants grown in the soil are normally exposed to a tremendous variety of organic compounds which have come directly from plant and animal residues in the soil, or indirectly from these residues through the action of soil micro-organisms. Depending upon their nature and concentration, and on the kind of the plant being grown, these substances may be innocuous, stimulatory, or inhibitory to plant growth"* (McCalla, Haskins, 1964: 202).

Kononova found exactly the growth inhibiting substances which Schreiner had found earlier (Kononova, 1961, cited by McCalla, Haskins, 1964).

Krasil'nikov found out that the wintertime is important for a further breakdown of toxic/growth inhibiting compounds and the subsequent growth of bacteria:

*"According to our observations, the microbial activity does not always cease in winter. Under a deep snow cover the earth is not always frozen and in such a soil microbiological processes take place. (..) Korenyako has shown that during the winter months of 1952–1954 certain species of actinomycetes (A. globisporus) grew more abundantly, in Moscow Oblast' soils, than during the summer and autumn.*

*Besides, certain biochemical processes, leading to detoxification of the soil take place in winter"* (Krasil'nikov et al., 1955).

*"The vigorous growth of microbes in spring is, according to our opinion, not only caused by the warm temperature and by moisture, but also by other factors. First, the toxins are inactivated or decomposed in winter due to low temperature. Second, low temperatures, as was noted above, stimulate the growth and activity of microbes. in addition, many soil nutrients under the action of low temperature, change and become more available to microbes"* (Krasil'nikov, 1958: 131, 132).

Bowditch also argues that the manure – enriched with earth and salt* – be spread in autumn and winter. Not in the spring. And with practical examples he shows that the yields are better than in the case of spreading the manure in the spring.

And Bowditch points to another advantage: if farmers fertilize in the fall and winter, the grasses start to grow in march. They develop their roots underground, invisible. And the farmers can harvest their grass in June. May and June are the best months because most grasses are in blooming in these months – so it is the time to mow. Mowing in July is too late. The grass quality is then less, more woody and less nutritive, and the chance of rain is much greater.

*"Early growth [of grass] is secured by having all the elements of nutrition thoroughly incorporated with the soil amongst the roots of the grasses, in such a state of decomposition that*

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* Common salt was a normal fertilizer these days. Bowditch: *"Common salt is included in every manure here recommended, because experience has shown its beneficial action upon grass whenever it has been properly applied, and because the analyses show that grass always contains both its elements, chlorine and sodium.*

*The quantity recommended is 1 cwt. per acre [roughly 100kg/ha], which Is more than a sufficient addition to the natural supplies for the largest crop of grass we can imagine as being reaped from an acre"* (Bowditch, 1858).

*they can be taken up by the roots as soon as the temperature of the earth and the air stimulate the plants into activity. That this occurs very early is certain, for by the following table we perceive that many of the grasses reach maturity in May, and most of them before the middle of June, and therefore we may safely assume that the manure should be well incorporated with the soil (not lying upon its surface), and sufficiently decomposed there to act efficiently in the middle of March"* (Bowditch, 1858).

In the same article, Bowditch gives an overview of the grasses, which farmers sowed these days: 21 in total, and of these there is only one flowering in July. Ryegrass is not on the list.

Manuring with stable manure in the summer is not recommended by Bowditch. The reason is interesting. In some districts, Bowditch saw farmers spreading solid manure in the summer. Then the grasses dwarfed, which didn't happen when spreading the same manure in the winter. Liquid manure is another story. He says this manure can be spread in the summer, but only if it is regularly alternated with fertilizing solid manure. Otherwise, liquid manure[*] results in a few sturdy grasses. The other grasses disappear:

"*My experience* [the experience of farmer Bywater in Leeds, cited by Bowditch]*, however, in the use of tank liquor as a dressing for grassland resulted in the discovery that by its exclusive application in successive years a very strong grass was produced, which appeared to destroy by its rankness the white clover and all the finer and more delicate kind of grasses; whilst a return to the use of farmyard manure, as a change, restored all the various kinds which had usually grown before*" (Bowditch, 1858).

And a last remark of Bowditch in this article concerns the use of sewage. It contains too much water, and the grass will rot quickly if not mown frequently, according to Bowditch. Bowditch advises to let it run into the oceans:

"*It is far better that the sewage of towns should run to waste into the ocean, than that our cultivators should apply it to the land and lose money by the application*".

But he also offered a better solution. Not only for liquid manure from the farms but also for human excreta. For the liquid manure, he advises to mix it with earth and finely sifted ash and 'other materials the farmer can command'. And for human excreta – the best manure for grasses – he advises the sprinkling of clay over it:

"*The present absurd water-carriage of excreta must be abandoned, and sewers employed for their legitimate purpose, viz., to carry away waste water to its natural receptacle the river. Moveable boxes should be attached to every house, and removed weekly in summer, fortnightly in winter. A cistern filled with dry pounded clay would be placed overhead, and a simple mechanical contrivance would throw down a measured quantity of this every time the handle was raised as water is now let down a closet. Nature's deodorizer and disinfectant would prevent the escape of injurious exhalations, and the refuse would be removed by water or other carriage some miles into the country, to await under sheds the farmer's season of use*" (Bowditch, 1858).

Later on in the UK this 'earth toilet' or 'earth closet' was really used. These were evaluated by a.o Voelcker. He published his very interesting results in 1872. Moule, he writes, had constructed, and patented several forms of earth closets. One of his conclusions was that earth toilets were only a good solutions in small towns and villages and for poor people. The earth in these toilets were only used to mix with excreta. Not with the urine. And this excreta rich earth had not a great fertilizing value. But the managers of prisons were very content with the earth toilets. All stench was gone now, and the hygiene in the prisons was much better. The urine in these facilities was collected in great tanks and sold. In his article are many interesting data, among others about the average composition of human excreta and urine in these days (Voelcker, 1872).

Future research.

Bowditch and Lawes have both a chemical view on the processes in the soil. They only talk about mineralization. Krasil'nikov points to the microbes: during the winter cold, the nutrients come available to the microbes (Krasil'nikov, 1958). An interesting question for future research is why the nutrients come available in the winter cold, and how the microbes consume their food in the winter. Do they eat organic compounds directly or do they mainly absorb inorganic nutrients? Or both? Fact is that Krasil'nikov points us to the microbial dimension of all the changes.

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[*] I suppose that liquid manure in these days was muck water or aalt, and not slurry.

The symbiotic phase.

At some point, after decay, the symbiotic phase begins in the soil. Under the influence of the poisonous and growth-inhibiting substances, in most farms in spring it gets going with fits and starts. The manure, spreaded in the spring, must first digest for a long time, the toxic components must be broken down, and the soil must also heat up sufficiently. And the symbionts must gain the upper hand over the putrefactive bacteria.

In turn, in spring, the symbionts must be fed with all kinds of root exudates from the plants in order to put them to work. The plants will probably grow slowly under the influence of the growth-inhibiting substances. The symbionts themselves also suffer from the ammonia, nitrate, hydrogen sulfide, phosphine, hydrogen chloride and all other secretions released by the work of the decay bacteria.

Paul et al. (2007) reported the following for the nitrogen fixers:

*“In addition, mineral nitrogen availability is known to reduce nitrogen fixation rates* (Sougoufara et al., 1990; Zuberer, 1998; Dianda, Chalifour, 2002) *and therefore TEM [Tuberculate Ectomycorrhizae, author] occurring in stands with high nitrogen availability may display lower nitrogenase activity ”*(Paul et al., 2007).

For the negative effects of ammonia and nitrate on nitrogen fixation, see also Lawes and Gilbert (1858), Reich et al. (1987), Poschenrieder and Lesch (1942) and Pfeiffer (1936).

But Jiang et al. (2020) differentiated into the amount of nitrate in relation to nitrogen fixation:

*“Our results showed that small amounts of nitrate (2.5 and 5 mM) promoted nodule formation and increased nodule biomass*[*]*, compared with plants in the 0 nitrate control treatment. In contrast, nitrate concentrations over 10 mM inhibited nodulation, resulting in reductions in nodule number and nodule biomass. Nodulation was completely inhibited by 15-mM nitrate in all the genotypes. Regression analyses indicated that 5-mM nitrate is the optimum concentration for promoting nodulation as measured by the total number of nodules formed, the number of effective nodules formed, and the nodule biomass formed”.* (Jiang et al., 2020).

According to Jones (2015), five kilogram nitrogen per hectare is the maximum you need for the support of nitrogen fixing bacteria, after a gradual reduction of artificial nitrogen fertilizer in say 3 years.

According to her fertilizing with higher amounts of inorganic nitrogen is not good for soil microbial life:

“*When inorganic nitrogen is provided, the supply of carbon* [from the plants, author] *to associative nitrogen fixing microbes is inhibited, resulting in carbon-depleted soils. Reduced carbon flows impact a vast network of microbial communities, restricting the availability of essential minerals, trace elements, vitamins and hormones required for plant tolerance to environmental stresses such as frost and drought and resistance to insects and disease*” (Jones, 2015).

The symbionts themselves must also have the right 'instruments' to convert the present organic and inorganic nitrogen compounds into compounds that are suitable for their own use. Microorganisms digest the material present. And for that, like plants and animals, they need enzymes. Cofactors are indispensable for enzyme formation. And these cofactors are the trace elements and some macro-elements like magnesium. These are becoming increasingly rare and/or they are no longer released from the soil particles. The latter is an important task of the mycorrhizae. But these have disappeared due to the superphosphate and unbound ammonia, nitrate, phosphine and hydrogen sulfide. Mycorrhiza and rhizobia use the same signaling mechanism.[†]

The work of Poschenrieder and lesch gives information about the influence of the different fertilizer combinations on root nodules:

Poschenrieder gives also an overview of authors, their findings and explanations from the beginning of the 20th century for the negative influence of nitrogen on nodulation.

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[*] Poschenrieder and lesch demonstrated that the biggest nodules do not have the highest nitrogen fixation. The smaller nodules gave higher yields (Poschenrieder, Lesch, 1942).

[†] “During evolution, the genetic programme for AM has been recruited for other plant root symbioses: functional adaptation of a plant receptor kinase that is essential for AM symbiosis paved the way for nitrogen-fixing bacteria to form intracellular symbioses with plant cells”(Parniske, 2008).

According to Rippel, cited by Pochenrieder and Lesch, the explanation of the inhibitory effect of nitrogen fertilizers on N fixation is the shortage of carbohydrates:

*"Heute wissen wir aus neueren Untersuchungen von Rippel, dass die geschwachte Knöllchenbildung der Leguminosen infolge Zufuhr von gebundenem Stickstoff mit einer Festlegung bzw. erhohten Beanspruchung der Kohlenhydrate durch die Pflanze, die sonst zur Ernahrung der Bakterien dienen, bei der durch die Stickstoffzufuhr gesteigerten Eiweissbildung in Verbindung zu bringen ist"*

And he summarises the results of the field trial in Bernburg as follows:

*"Die Stickstoffdüngung übte eine stark hemmende Wirkung auf die Knöllchenbildung aus, die insbesondere bei der einseitig mit Stickstoff gedüngten Versuchsreihe sowie bei der Stallmist plus NPK-Düngung sowohl in einer Abnahme der Knollchenzahl als auch des Knollchengewichtes in Erscheinung trat"* (Poschenrieder, Lesch, 1942). This is very visible in Table 3.

**Table 3**. Nutrient intake in the nodules of in total 100 plants[*]

| Manuring | $K_2O$, mg | $P_2O_5$, mg | N, mg |
|---|---|---|---|
| Control | 459 | 354 | 1525 |
| N | 109 | 100 | 437 |
| P | 886 | 649 | 2790 |
| K | 551 | 41 7 | 1751 |
| PK | 883 | 631 | 2710 |
| NK | 174 | 142 | 645 |
| NP | 371 | 324 | 1488 |
| NPK($NH_4$) | 263 | 197 | 809 |
| NPK($No_3$)[†] | 239 | 176 | 750 |
| FYM | 525 | 368 | 1682 |
| FYM+PK | 467 | 303 | 1272 |
| FYM+NPK | 142 | 102 | 435 |

My conclusions based on the amounts in milligrams (whereby the N in the nodules is from N fixation):

1. The highest N fixations is in the treatments with pure P and P + K.
P+K gives somewhat less than pure P.
2. The least N fixation – 435 – is with the most complete fertilizer: FYM + NPK. Followed by pure N (437) and NK (645) respectively;
3. NP gives a N fixation of 1488 mg – 47 % and 45 % less than pure P and PK respectively;
4. K, FYM , FYM + PK, and NP give comparable fixation yields. But in fact these N-yields are almost no yield. Because only K and FYM give somewhat higher N Fixation yields than the Control (1525);
5. Compared to the Control N, NK, NP, NPK($NH_4$), NPK($No_3$) FYM + PK, and FYM+NPK give a negative N fixation yield.

So, ammonium, nitrate and [FYM + NPK] are counteracting N fixation. Only farmyard manure, and pure potassium give a somewhat higher N fixation than the control.

Phosphor is the real stimulans for nitrogen fixation. Especially N is counteracting it and even K is somewhat counteracting: PK gives less N fixation than pure P.

The yields are very interesting for my research into the causes of the lower yields in organic agriculture. Wabersich has published the yields for potatoes in this long term trial in Bernburg (Wabersich, 1967).

These results are in accordance with those of Lawes and Gilbert (1858). In a three year trial with seventeen different treatments lawes investigated what were the differences in yields and qualities in meadowland. One of their findings was that the legumes grew very well on the

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[*] Here I have left out the columns with the nutrient contents (percentages) of the original table in Poschenrieder and Lesch (1942).

[†] Sodium nitrate or Chilisalpeter.

treatment with only minerals (K + Na + P + Ca +S + Mg; no ammonium, nor nitrate), and that in all the treatments with nitrogen, the grasses grew well, but the legumes disappeared almost completely, and very quick:

*"That the effect of a mixed, but purely mineral manure, upon the complex herbage of permanent meadow land, was chiefly to develop the growth of the Leguminous plants it contained ; and scarcely at all to increase the produce of the Graminaceous plants, or commonly called Natural Grasses.*

*That the action of purely nitrogenous manures, upon the permanent meadow, was to discourage the growth of the Leguminous herbage, and to increase the produce of the Graminaceous hay.*

*That by the combination of both nitrogenous and proper mineral manures, the produce of Graminaceous hay was very much increased. In the particular soil and seasons in question, the increase obtained by the combination was far beyond the sum of the increase yielded by the two descriptions of manure, when each of them was used separately.*

*That farmyard manure gave a considerable increase of chiefly Graminaceous hay. In the soil and seasons in question, however, the artificial combination of nitrogenous and mixed mineral manure yielded a very much larger increase than an annual dressing of 14 tons of farmyard manure. (pp. 571-572).*

*(..) In fact, where the ammoniacal salts were employed, the increase was exclusively due to the increased growth of Graminaceous plants—the so-called Natural Grasses – there being scarcely a Leguminous plant to be found upon the plot (page 561).*

*(..) Indeed, notwithstanding the large amount of mineral constituents, and especially of silicious compounds, contained in the cut wheat-straw*[*]*, as compared with the sawdust, there was, whether compared with the produce by the mixed mineral and nitrogenous manure, or with that by the mixed mineral and nitrogenous manure and sawdust, an average annual deficit of 4 to 5 cwts. of first-crop hay, where the cut wheat-straw was employed (page 563).*

*(..) It will be shown, on a future occasion, that the percentage of nitrogen in the dry substance of the hay, grown both by ammoniacal salts alone, and by nitrate of soda alone, was comparatively very high—in fact, considerably higher than when the mineral manures were also employed, whereby the Graminaceous produce was much increased. So far then as there was an excessive amount of nitrogen, in the form of elaborated nitrogenous vegetable compounds, where the supplied nitrogen was liberal—the mineral constituents in defect—and the growth restricted thereby—it was that there was a relative deficiency in the formation of the nonnitrogenous vegetable substances (page 566).*

*(..) But it may be here stated in passing, that the crop grown by the larger amount of ammoniacal salts—supplying as it did the enormous quantity of 200 lbs*[†]*. of ammonia per acre per annum—was so over-luxuriant, as to be much laid, matted together, 'and dead at the bottom, some time before the bulk was ready for cutting" (page 564)* (Lawes and Gilbert, 1858).

The farmyard manure in these trials was spread in november and december, the previous year.

Not only nitrogen salts form a risk for plants. The same applies to other plant nutrient salts like potassium chloride (Khan et al., 2013) and superphosphate (Jamieson, 1910). In fact, this is true for all easily soluble salts[‡]. NPK dominates in almost all fertilizer programs. Often combined with chloride, calcium and/or sulphur, and sometimes with magnesium also.

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[*] In this treatment – plot 12 – lawes and Gilbert had given 2000 lbs cut wheat straw plus 200 lbs ammonia sulphate and 200 lbs ammonia murate. This result is comparable with that of McCalla whos also saw a negative influence of wheat straw on the yields (McCalla, Haskins, 1964). But McCalla noticed also a simpler explanation, namely that the wheat straw took part of soil nitrogen for its breakdown bij microbes. But his own research showed also the toxic compounds in wheat straw (Guenzi, McCalla, 1962).

[†] In fact it was not 200 lbs of ammoniacal salts but 400. There was no treatment with 200 kg, only 400. And even one – T 13 – treatment with 800 kg of the two ammoniacal salts. In fact, the tekst is somewhat confusing. In the overview lawes writes: '200 lbs, each, Sulphate and Muriate Ammonia". From the tekst I concluded that you must read this as: 200 lbs sulphate ammonia, plus 200 lbs muriate ammonia.

[‡] Seasalt can be given as a folium fertilizer provided that less than 2000 ppm is given. In coastal areas – max 25 kilometer from the sea – seasalt, brought by the wind and rain from the seaside, precipitate. I don't know

**Vitamin C**

An additional effect of using nitrate or ammonium is that the plants form less vitamin C (Visser, 2010). Vitamin C is an important compound for the natural resistance of plants (Locato et al., 2013), just as in animals and human beings. Visser quotes Wittwer's research here:

*"In the 40s a broader recognition wins ground that not all is well with nitrogen fertilizer use, eg Wittwer* et al.* (1945)*, giving 'evidence of an inverse relationship between the concentration of vitamin C in plant tissue and nitrogen supplied as fertilizer" (*Wittwer, 1945; Visser, 2010: 193*).*

This sheds new light on the question of why the differences in vitamin C content between conventional and organic agriculture are so small in many studies (Bourn and Prescott, 2002; Wunderlich et al., 2008). If the organic crops do indeed grow at the moment for the biggest part on mineralized nitrogen, as supposed by their scientists, little difference can be expected in this respect from the crops in conventional agriculture. All the more reason to maximize plant growth with the help of organic nitrogen.

Vitamin C was also measured in a TNO/WUR study in 2007 when comparing conventional and organic chicken feed (corn, peas and wheat). The organic food had 10 % less protein and less vitamin B5 and vitamin C.

And these were the results from a study by the same organization in 2006. In this study, the differences for vitamin C and nitrate in 15 organic and conventional vegetables were statistically not significant. Although there were big differences for some vegetables. Only statistically significant differences were found for the dry matter content and dietary fiber. Both were higher in the organic products (Kramer, 2006).

But a more recent international meta-study gives a different result. Especially for flavonoids and carotenoids, organic scores remarkably well here:

*"A few years ago, the results of more than 300 studies into differences in the composition of organic and non-organic vegetable foods were listed. Organic products were found to contain more antioxidants, such as 19-69 % more flavonoids, 17 % more carotenoids and 6 % more vitamin C. Remarkably, the content of vitamin E, also an antioxidant, was just 15 % lower. Antioxidants protect body cells against damage and may therefore reduce the risk of diseases "* (Rolvink, 2019).

Though, according to Dangour et al. (2009) there are no differences between organic and conventional crops, except for nitrate, magnesium and zinc, phytochemicals and sugars.

*"In analysis including all studies (independent of quality), no evidence of a difference in content was detected between organically and conventionally produced crops for the following nutrients and other substances: vitamin C, calcium, phosphorus, potassium, total soluble solids, titratable acidity, copper, iron, nitrates, manganese, ash, specific proteins, sodium, plant non-digestible carbohydrates, β-carotene and sulphur. Significant differences in content between organically and conventionally produced crops were found in some minerals (nitrogen higher in conventional crops; magnesium and zinc higher in organic crops), phytochemicals (phenolic compounds and flavonoids higher in organic crops) and sugars (higher in organic crops).*

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if other salts also can be given as foliar fertilizer. In general you can say that organically bound elements are safer than salts.

* In 1947 Wittwer published a follow-up study on vitamin C and fertilizer for peaches (Wittwer, 1947). Comis (1989) descibes the research findings of Sharon Hornick. And he states: "*Reports of decreasing vitamin C with increased use of nitrogen surfaced in the 1940's with studies on grapefruit. But the availability of cheap nitrogen fertilizer in the 1950's suppressed concerns about quality in favor of yields. Hornick says she has seen renewed interest in crop quality in the 1980's as farmers search for ways to cut chemical use, both to save money and to prevent possible pollution of the groundwater*". The influence of ammonia and nitrate on the other vitamins is as far as I know not investigated. Weston Price compared traditional and modern Western dairy products, and stated that the levels of vitamin A and K2 are much lower in the products in the western countries (Masterjohn, 2008). But Weston Price did not investigate the influence of artificial fertilizers. Vitamin K2 prevents, together with vitamin D and vitamin A the calcification of the weak parts of our body, and they protect at the same time our bones and teeth against discalcification. In the dutch butter the vitamin A content is today indeed low. The milk contains 2,5 times less vitamin A, according to data from Friesland Campina, the dutch Dairy cooperative. The Dutch butter has no longer its typical yellow color in the spring.

*In analysis restricted to satisfactory quality studies, significant differences in content between organically and conventionally produced crops were found only in nitrogen content (higher in conventional crops), phosphorus (higher in organic crops) and titratable acidity (higher in organic crops)"* (Dangour et al., 2009).

For livestock products there were found differences for some fats and fatty acids. These were higher in organic products, The same for nitrogen in these products.

De Waart (1998) comes to a somewhat different conclusion for nitrate and vitamin C in organic and conventional products than Dangour:

- Nitrate in organic products is the same or lower than in conventional products;
- Vitamin C in organic products is the same or higher than in conventional products;

And based on some studies she concluded that more nitrogen fertilizer resulted in higher nitrate contents and lower vitamin C contents – an inverse relation.

*"As a consequence of a lower nitrogen supply*[*] [in organic agriculture, Author] *and the slower availability of it ( ..) is the ripening phase longer compared to the growth phase. This is reflected in a lower yield, a lower nitrate content, a better taste and a higher vitamin C content"* (de Waart, 1998).

See also Rosen (2010) and Magkos et al. (2006). Rosen made an overview of the health claims by the proponents of organic food. He was not convinced that these claims are right. The debate goes on.

- **Imbalance of the cations**

Furthermore, an excess of potassium impedes to a certain degree the absorption of divalent cations, such as calcium, magnesium, boron (Rinsema, 1981: 81), manganese, zinc and iron[†], but also of the monovalent sodium (for sodium see Arney et al., 1995). On this basis, I suspect that too much potassium also slows down the absorption of the other monovalent and divalent trace elements. Van Baren for instance states that too much potassium inhibits the absorption of silicon (Van Baren, 1934). As a result, the wheat plants at that time got limp stems and there had to be bred short-stemmed varieties. A plant needs enough silicon to protect itself and to keep the stems straight.

Also ammonium hinders the uptake of divalent cations (Britto and Kronzucker, 2002). Because potassium and ammonium are often given together, and because ammonium and potassium use the same entrance in the root cells, it is not clear if the reduced absorption of the other cations is caused by potassium or by ammonium, or by both. Fact is that in many crops the level of potassium is extremely high, and calcium, magnesium and sodium are relatively low (Nigten, 2019c).

German organic dairy farms.

Based on thirteen years of measurements of the grass of organic dairy farms throughout Germany, we know that on average these farms have too much potassium in the grass and too little sodium, calcium and magnesium.

The deviation of the German organic dairy farm silage from ideal ratios is particularly large for potassium. Also the spread is great. The content of potassium in the silage is from 2.5 to 53.8 g potassium/kg DM, with an average of 25.3 g potassium/kg DM. The spread for the other elements was significantly smaller. In 2014, the Dutch average for 1854 dairy farms was 35.2 grams potassium/kg DM. Here too, outliers of 5 to 55 grams potassium/kg DM (DMS, 2015).

The ratios in this German Bio-grass silage are as follows (Table 4).

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[*] In many cases we see that the total amount of nitrogen given in organic agriculture is not necessary lower than in conventional agriculture. It is indeed slower to be available, as de Waart states.

[†] The knowledge about the reduced absorption of zinc, manganese and iron due to an excess of potassium is based on practical experience in Dutch greenhouse horticulture. That is why they provide extra zinc and iron in their hydroponics. The Benton practice guide confirms this (Benton, Jones, 2004*). "High concentrations* [of potassium] *interfere with the function Fe, Mn, and Zn. Zinc deficiencies often are the most apparent".* The Mulder map contradicts this. However, this card concerns normal doses (Nigten, 2019c: 22). A high phosphate concentration can also inhibit the absorption of iron and zinc (Royal Brinkman, 2020).

**Table 4.** Organic dairy farms in Germany. Results for silage (Grünlandsilage) 1997-2010 (data from Leisen, 2011)

| The average amounts in the silage (g/kg DM) | Ratio of cations | Ideal ratio's[*] | Real ratio's in the german silage |
|---|---|---|---|
| | K / Mg | 2-5 | 14.88 |
| K = 25.3 | K / Na | 2-4 | 25.3 |
| Na = 1 | Ca / Mg | 1-2 | 4.05 |
| Mg = 1.7 | Ca / P | 1-2 / 1-3[†] | 2.23 |
| Ca = 6.9 | Mg / (K+Ca+Na+P) | 0.10-0.25 | 0.046 |
| P = 3.1 | N / S | 12-15 | Unknown. N and S have not been measured |

So sodium and magnesium are too low in these grass silages, and potassium is much too high. Sodium and magnesium are necessary for a good conversion of non-protein nitrogen (NPN) and non-protein sulphur (NPS) in real proteins (Chiy, Phillips, 1993). Too much NPN and NPS in fodder and concentrate are a heavy burdening of the liver and the kidneys of the animals. So the imbalance of the cations has a direct effect on the grass quality and the health of the animals.

In a Swedish study was shown that the cattle in organic farming get even much more too little sodium than cattle in conventional farming. The cows on organic farms in Sweden need on average 17 gram per day extra salt against 3,3 to 6,6 gram on conventional diets. 17 gram per day is – for health reasons – too much via the licking of salt (Johansson, 2008). So for these cows salt fertilizing in the pastures is necessary. Salt through the ryegrass has many advantages:

"*Increased herbage digestibility, promoted growth of bacteria that digest fibres in the rumen,*

*increased milk yield and decreased somatic cell count are results of using sodium as a fertiliser according to one author*" (Johansson, 2008).

Nitrogen and sulfur in the German biogras silage have not been measured, nor their specific compositions. That is an important omission. The levels of non-protein-bound nitrogen and sulfur (NPN and NPS[‡]) in particular say a lot about the quality. Inorganic N fertilization weakens the plants, comparable to atmospheric N deposition:

"*According to Phoenix et al.* (2012)*, [inorganic] N deposition leads to an increase in the susceptibility of plants to secondary stresses, i.e. increased herbivory, reduced resistance to attack by pathogens or increase in susceptibility to drought or freezing damage*" (cited by Anjana, Umar, 2018: 5).

The iron and manganese levels in the German silage are (very) high, and the copper, selenium and zinc levels are (too) low. Selenium is very low. But the spread is great for all trace elements.

Also for the trace elements, the grass silages are out of balance.

In the next article, I will elaborate on the consequences.

## 3. Conclusion

Beside N fertilization with ammonia, nitrate or urea plants can collect organic nitrogen with the help of symbiotic microbes, or directly by themselves without this help – in particular the plants who naturally don't have mycorrhizal symbionts. The symbiotic microbes, which collect or produce nitrogen (and other anions), are living inside the plants or outside. Many of them are

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[*] To substantiate these optimal ratios, I refer to an article of my hand from 2018, "Reinventing agriculture" (Nigten, 2018).

[†] Some authors believe that a Ca/P ratio of up to 3 does not yet lead to problems (Bredon, Dugmore, 1985). Most assume a ratio maximum of 2 (ARC, 1980).

[‡] NPN and NPS are abbreviations for Non Protein Nitrogen and Non Protein Sulphur – jargon for nitrogen and sulphur compounds which are not proteins. Maybe also phosphor should be protein-bound.

nitrogen fixers but there are also symbionts which free the nitrogen from the soil particles, from the humic and fulvic acids or other organic matter and bring it into the plants. The source of the nitrogen, which these symbionts consume, can be organic or inorganic, but after the consumption by these microbes, all the nitrogen is organic: microbial protein.

In all these cases, except for the fertilization with nitrogen containing salts, the plants get their nitrogen in an organic form. Directly by the uptake of amino acids, nucleic acids or protein, and indirectly by 'consuming' their symbionts.

Under favorable conditions, plants – all plants – can also fix themselves nitrogen from the air, with special hairs on their leaves. But ammonia and nitrate impede this when the amounts in the soil are too high.

Nitrogen salts are a risk for plants, because the plants have difficulties in getting not too much of it. Too much nitrogen salts can result in non-protein nitrogen in the plants. The same for sulphur and phosphor salts. They weaken the plants and make them vulnerable for pests and diseases. Too much nitrate and ammonia in the crops implies also health risks for animals and men who eat them.

Inorganic fertilizers repress the Plant Growth-Promoting Rhizobacteria.

But at the same time not all organic nitrogen compounds are a good food for plants. Many rotting products from manure, slurry and warm compost also disturb, or delay, or slow down the growth of plants. The putrefactive bacteria, which are producing the rotting, are overruling the symbiotic bacteria. A great deal of the nitrogen in animal dung and warm compost is lost into the environment. Probably, even more than from artificial nitrogen fertilizers. Here is one of the reasons why organic agriculture has lower yields than conventional agriculture.

By adding earth to the animal dung or the vegetal residuals, the rotting and the losses stop.

Sodium, silicon and many trace elements are missing or insufficient[*]. In most crops, also magnesium and calcium are too low[†], because high levels of potassium and ammonium hinder partly the uptake of magnesium, calcium, sodium and trace elements. Extra sodium and magnesium are necessary to counterbalance potassium and for a good NPN and NPS conversion in real proteins. Too much iron and manganese are also a risk for the crops and the animals, which eat them.

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[*] The review of Dimkpa et al gives a good overview about the roles and the importance of trace elements for plants, animals and humans (Dimkpa, Bindrapan, 2016).

[†] Fan et al studied the mineral contents of wheat at the Broadbalk wheat experiment: "The concentrations of zinc, iron, copper and magnesium remained stable between 1845 and the mid 1960s, but since then have decreased significantly, which coincided with the introduction of semi-dwarf, high-yielding cultivars" (Fan et al., 2008).

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## Appendix 1

### The discovery of the nitrogen fixing hairs on all plants by Jamieson.

Jamieson:

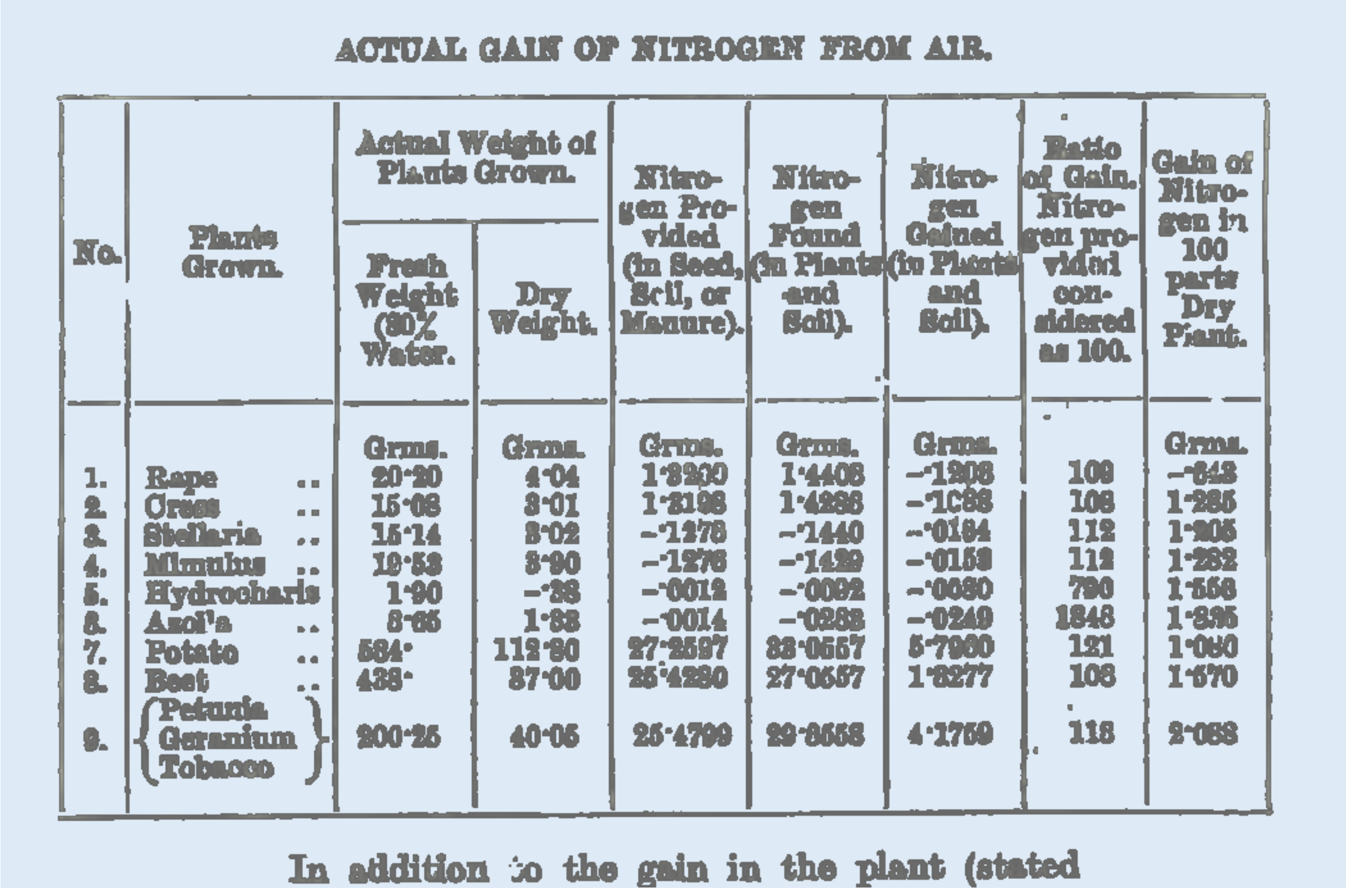
*"Search for them* [the hairs. author]*, though attended frequently with failure, at first, has, in every case, after persistency, been followed by success in finding them in one place or other, if not in the edges, or back, or ribs of the leaf, then on the young stalk, or the leaf scales, &c. So also, absolute failure to find them on some plants, such as legumes, was followed by success on searching at a certain stage of growth, i.e., the leaves just as they emerge from the buds—Later on they disappear, being absorbed into the leaf. The organs have now been found on a large number of the most unlikely plants (on which nothing akin to glandular hairs had been recognised), such as hard-leaved pines. In short, on no plant as yet thoroughly examined has the search been unsuccessful, and evidently therefore we have here not an occasional occurrence (as in the case of the so-called glandular hairs), but a general occurrence to ensure the provision of the substance most essential to life—viz. nitrogen to form albumen.*

*This constant occurrence was a strong feature in the evidence. Had it not been found, in one form or other, on every plant examined, there would have been a weakness in the chain of evidence, more especially if the absence applied to a highly nitrogenous plant, such as any legume; and long and trying was the vain search for it on legumes. Had a legume been chosen first, as from its high nitrogen content it might probably have been, the discovery would almost certainly not have been made, and the investigation would probably have been given up. At last, on the edge of a leaf, a minute knob was observed which was unusual, and close examination brought out that it possessed the specific characters of an absorber, but in this case submerged in the fleshy leaf ; remains of numerous similar structures altogether submerged were then seen; it thus appeared that the examination must be made at an earlier stage. Seedlings were therefore raised and examined, when, instead of any difficulty in finding the absorbing organs, they now appeared at once and in abundance, standing up like a forest and in the usual typical form. This event was one of the most convincing features in the progress of the work—it gave confidence of being on the right track* (..).

*They* [the hairs. Author] *have a definite and special character, a general resemblance in structure, and frequent resemblance in form, and although the form varies greatly in different plants, the specialised character always remains. The usual structure is a long blunt projection divided into* *sections, like a finger with its joints (as in Spergula), the lower sections being at first (and for some time) colourless, transparent, empty, and double walled ; the highest section, which is very often distended into a bulb or club-head-like form (as in legumes and geranium), is altogether different in appearance and distinctive in character from the lower sections, by containing yellowish-green matter resembling chlorophyll, but probably differing from chlorophyll ; it is the active and essential part of the organ, and it shows very marked changes during its period of activity or life. This is to say—the highest section of these structures, and it alone, is at first filled with this yellowish-green chlorophylllike matter, and, even when just fully formed, it shows no presence of albumen by the usual tests; gradually, however, that highest section, and that section alone, becomes charged with albumen, and ultimately is gorged with it ; the albumen then passes down through the open ends of the sections into the vascular system of the plant.*

*These absorbers are found in all stages of growth in regard to albumen contents, i.e. absent, filling, filled, gorged, and emptied; frequently (as in the poplar and sycamore) they occur in groups, in which all these stages can be observed at one glance according to the varying age of the members of the group. Very often (as in potato) there are two forms on one plant, as if showing a reserve to ensure the provision of nitrogen, just as in plants there is frequently a, reserve method to secure reproduction (i.e. flowers and leaf buds, runners, &c.)".* (Jamieson, 1910, page 95 and beyond).

On page 106 of his book you can find the results of a series of trials done by Jamieson:



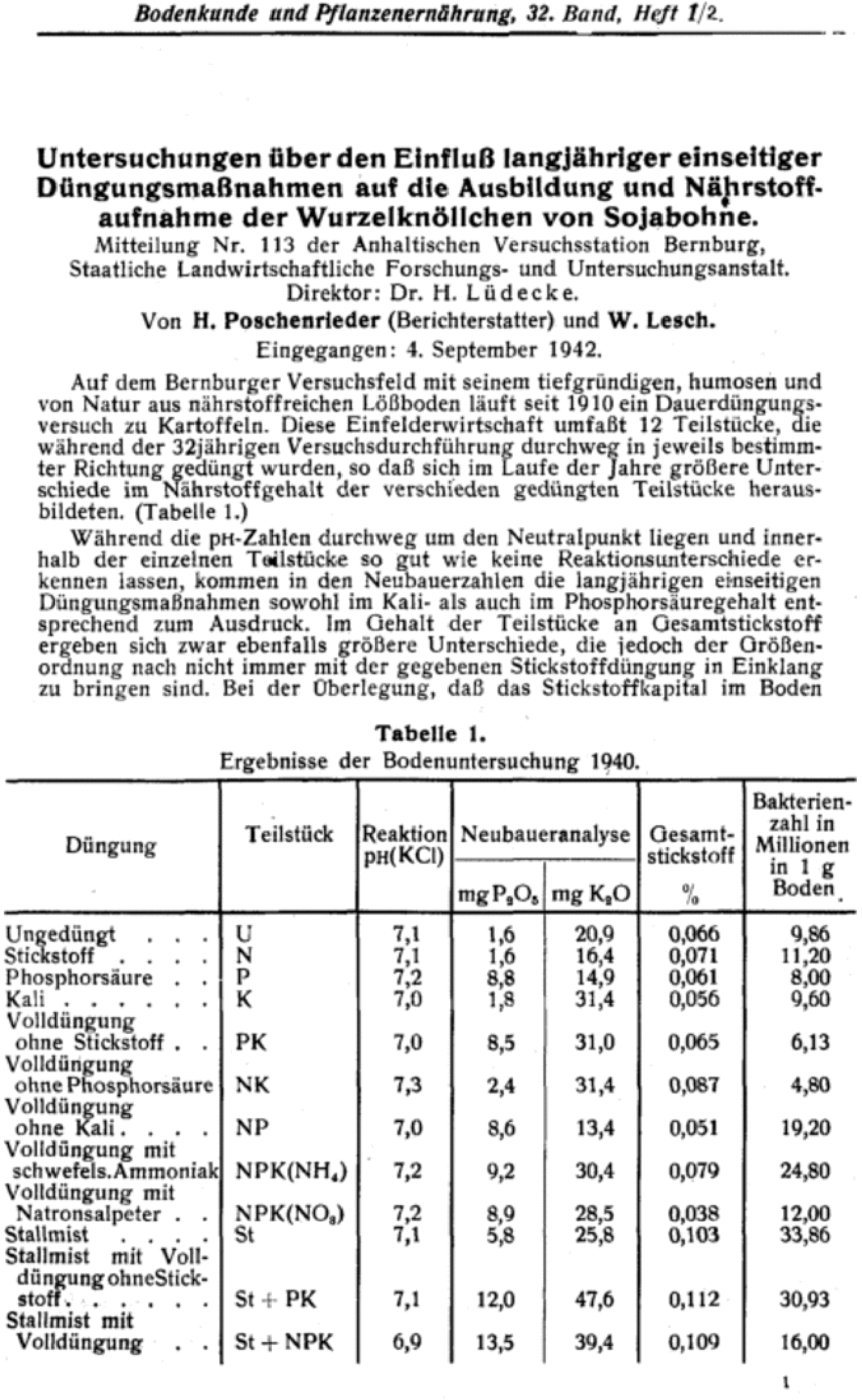
ACTUAL GAIN OF NITROGEN FROM AIR.

| No. | Plants Grown. | Actual Weight of Plants Grown. | | Nitrogen Provided (in Seed, Soil, or Manure). | Nitrogen Found (in Plants and Soil). | Nitrogen Gained (in Plants and Soil). | Ratio of Gain. Nitrogen provided considered as 100. | Gain of Nitrogen in 100 parts Dry Plant. |
|---|---|---|---|---|---|---|---|---|
| | | Fresh Weight (80% Water. | Dry Weight. | | | | | |
| | | Grms. | Grms. | Grms. | Grms. | Grms. | | Grms. |
| 1. | Rape .. | 20·20 | 4·04 | 1·8200 | 1·4408 | –·1208 | 109 | –·843 |
| 2. | Cress .. | 15·08 | 3·01 | 1·3198 | 1·4286 | –·1088 | 108 | 1·285 |
| 3. | Stellaria .. | 15·14 | 3·02 | –·1278 | –·1440 | –·0164 | 112 | 1·205 |
| 4. | Mimulus .. | 19·53 | 3·90 | –·1276 | –·1429 | –·0153 | 112 | 1·282 |
| 5. | Hydrocharis | 1·90 | –·38 | –·0012 | –·0092 | –·0080 | 790 | 1·558 |
| 6. | Azol'a .. | 8·65 | 1·83 | –·0014 | –·0263 | –·0249 | 1843 | 1·395 |
| 7. | Potato .. | 564· | 112·80 | 27·2597 | 33·0557 | 5·7960 | 121 | 1·030 |
| 8. | Beet .. | 438· | 87·00 | 25·4280 | 27·0557 | 1·6277 | 106 | 1·670 |
| 9. | Petunia<br>Geranium<br>Tobacco | 200·25 | 40·05 | 25·4799 | 29·6558 | 4·1759 | 118 | 2·063 |

In addition to the gain in the plant (stated

## Appendix 2

## Fertilizer trials in Bernburg, Germany: the effects of different fertilizers on the bacterial count, and the soil nitrogen content



*Bodenkunde und Pflanzenernährung, 32. Band, Heft 1/2.*

### Untersuchungen über den Einfluß langjähriger einseitiger Düngungsmaßnahmen auf die Ausbildung und Nährstoffaufnahme der Wurzelknöllchen von Sojabohne.

Mitteilung Nr. 113 der Anhaltischen Versuchsstation Bernburg,
Staatliche Landwirtschaftliche Forschungs- und Untersuchungsanstalt.
Direktor: Dr. H. Lüdecke.

Von **H. Poschenrieder** (Berichterstatter) und **W. Lesch.**

Eingegangen: 4. September 1942.

Auf dem Bernburger Versuchsfeld mit seinem tiefgründigen, humosen und von Natur aus nährstoffreichen Lößboden läuft seit 1910 ein Dauerdüngungsversuch zu Kartoffeln. Diese Einfelderwirtschaft umfaßt 12 Teilstücke, die während der 32jährigen Versuchsdurchführung durchweg in jeweils bestimmter Richtung gedüngt wurden, so daß sich im Laufe der Jahre größere Unterschiede im Nährstoffgehalt der verschieden gedüngten Teilstücke herausbildeten. (Tabelle 1.)

Während die pH-Zahlen durchweg um den Neutralpunkt liegen und innerhalb der einzelnen Teilstücke so gut wie keine Reaktionsunterschiede erkennen lassen, kommen in den Neubauerzahlen die langjährigen einseitigen Düngungsmaßnahmen sowohl im Kali- als auch im Phosphorsäuregehalt entsprechend zum Ausdruck. Im Gehalt der Teilstücke an Gesamtstickstoff ergeben sich zwar ebenfalls größere Unterschiede, die jedoch der Größenordnung nach nicht immer mit der gegebenen Stickstoffdüngung in Einklang zu bringen sind. Bei der Überlegung, daß das Stickstoffkapital im Boden

**Tabelle 1.**
Ergebnisse der Bodenuntersuchung 1940.

| Düngung | Teilstück | Reaktion pH(KCl) | Neubaueranalyse | | Gesamtstickstoff | Bakterienzahl in Millionen in 1 g Boden. |
|---|---|---|---|---|---|---|
| | | | mg $P_2O_5$ | mg $K_2O$ | % | |
| Ungedüngt . . . | U | 7,1 | 1,6 | 20,9 | 0,066 | 9,86 |
| Stickstoff . . . . | N | 7,1 | 1,6 | 16,4 | 0,071 | 11,20 |
| Phosphorsäure . . | P | 7,2 | 8,8 | 14,9 | 0,061 | 8,00 |
| Kali . . . . . . | K | 7,0 | 1,8 | 31,4 | 0,056 | 9,60 |
| Volldüngung ohne Stickstoff . . | PK | 7,0 | 8,5 | 31,0 | 0,065 | 6,13 |
| Volldüngung ohne Phosphorsäure | NK | 7,3 | 2,4 | 31,4 | 0,087 | 4,80 |
| Volldüngung ohne Kali . . . . | NP | 7,0 | 8,6 | 13,4 | 0,051 | 19,20 |
| Volldüngung mit schwefels. Ammoniak | NPK($NH_4$) | 7,2 | 9,2 | 30,4 | 0,079 | 24,80 |
| Volldüngung mit Natronsalpeter . . | NPK($NO_3$) | 7,2 | 8,9 | 28,5 | 0,038 | 12,00 |
| Stallmist . . . . | St | 7,1 | 5,8 | 25,8 | 0,103 | 33,86 |
| Stallmist mit Volldüngung ohne Stickstoff . . . . . . | St + PK | 7,1 | 12,0 | 47,6 | 0,112 | 30,93 |
| Stallmist mit Volldüngung . . | St + NPK | 6,9 | 13,5 | 39,4 | 0,109 | 16,00 |

1

The highest bacterial count is in Farmyard manure, and Farmyard manure plus PK. The second group is NPK ($NH_4$ (which contains also sulphur)); NP, and FYM + NPK. The third group has a bacterial count comparable to the control ( some with a somewhat higher, and some with even less bacterial count: N; P; K: NK; PK;. And NK and PK have the lowest bacterial count.

If we have a more close look at the three farmyard manure treatements (FYM; FYM + PK, and FYM + NPK we see that the last one has a low bacterial count compared to the two other treatments. So the influence of the extra mineral N on the bacterial count is strongly negative, comparable to the effect of N on nodulation.

The result of the soil nitrogen content measurements are also interesting for organic agriculture, because the highest soil nitrogen content is in the three farmyard manure treatments: Stallmist (FYM); Stallmist +PK; and Stallmist + NPK: 0,103; 0,112 and 0,109 respectively. Poschenrieder comments as follows:

*"Die merklich höheren Stickstoffwerte der Stallmistteilstücke jedoch finden ihre Erklärung einerseits in der wesentlich niedrigeren Ausnutzung des Stallmiststickstoffs durch die hoheren Pflanzen. Aus diesem Grunde bleiben im Boden relativ grössere Mengen an Stickstoff zuruck. Anderseits unterliegen die im Stalldünger als Bestandteile des unverrotteten Düngers und der Mikroorganismen festgelegten Stickstoffverbindungen weniger der Auswaschung als die in mineralischer Form gegebenen Stickstoffmengen"* (Poschenrieder, Lesch, 1942).