Perceptions of plant nutrition in agriculture

Some consequences for soil fertility, human health and global nutrition,

an essay in contextualisation

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Summary

Our conceptual 'plant model', that is the way we envisage plants and think about them, coins our treatment of crops – and thus also soils – in agriculture.
The more we see plant growth as mainly depending on the uptake of soluble inorganic N-, P- and K-compounds, the more we will want to provide the soils they grown in with soluble nutrients as fertilisers, to increase their growth and thereby our harvest.
However, the more we learn to see plant's growth as their active uptake of organic molecules and even plasma, wherein the nutrients are C-bound, the more we will provide the crops with soil ecosystems wherein they can find those nutrients, stored in life cycles of growing and decaying soil organisms. Better soil ecosystems warrant better yields, is a shortcut representing this circular long-time plant model – a vision.

In this paper I will present literature on some historic roots and some actual effects in practice of circular long-time agriculture and its perspectives to feed the world.

Introduction

The roots of plants are obviously hidden from our direct observation as they grow into the darkness of the soil. That plain fact hampers our immediate understanding of what they actually do, and how.
Plant growth research in glassware is a helpful tool, but it creates a crucial artefact: in the laboratory as well as in our minds. We apply 'pure' chemicals that we presume to be plant nutrients, to find out which of them are needed. But using this presumption and its experimental setting, we can only find that plants indeed use (and thus 'need') soluble nutrients, which they absorb with sets of identical roots, in a uniform environment.
In this paper I choose for the concept wherein plants grow in soils that are seen as ecosystems or, in other words, in 'living' soils. Amelioration of the farms' soils is in that concept the prime goal of the farmer, with the overall objective to have ever better harvests by ongoing improvement of precisely those soils. These soils then again are seen within the farms biotope as a whole, in the farm's landscape, which includes all environmental compartments[i]. Plants in that concept represent self-organising potentials. Plants which in their development proceed through successive stages of realisation[ii], using clever and diversified root systems[iii].
In agro-ecological farming systems, like organic-, permaculture and biodynamic-agriculture, farming for better soils is widely practiced as a common interest[iv]. Moreover, those farming systems even serve the consumers economy.[v]

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Agriculture and soil-fertility building

An old ethic of farmers was to leave your successor a better soil then the one you bought or inherited from your predecessor. Building soils, that is: upgrading soil fertility, was the one and only way to make sure yields would go on improving for generations. Improving soils was also the key to pest prevention.
However, the intensification of agriculture with high external inputs - instead of local resources recycling - during the decades following World War II in the United States and Europe led to a huge decrease in the number of farms and a correlated increase in their surface area. It also resulted in a massive use of mainly chemical and some organic fertilizers. These practices have led to high nitrogen concentrations in soils and in surface water and groundwater ($NO3^-$ and $NH4^+$)[vi], but also to soil compaction[vii] (ploughing) and toxification (pesticides) of humans and the environment[viii].
However, there is quite a body of knowledge on how to implement a soil building agriculture. And not only in the field of organic agriculture. Let me quote from the handbook of soil scientists Fred Magdoff and Harold van Es[ix]:
“Although the details of how best to create high-quality soils differ from farm to farm, and even from field to field, the general approaches (for good, that is carbon enriching soil management) are the same – for example:
• Implement a number of practices that add organic materials to the soil.
• Add diverse sources of organic materials to the soil.
• Minimize losses of native soil organic matter.
• Provide plenty of soil cover—cover crops and/or surface residue—to protect the soil from raindrops and temperature extremes.
• Minimize tillage and other soil disturbances.
• Whenever traveling on the soil with field equipment, use practices that help develop and maintain good soil structure.
• Manage soil fertility status to maintain optimal pH levels for your crops and a sufficient supply of nutrients for plants without resulting in water pollution.
• In arid regions, reduce the amount of sodium or salt in the soil.”
They emphasise however that “As soil organic matter decreases, it becomes increasingly difficult to grow plants, because problems with fertility, water availability, compaction, erosion, parasites, diseases, and insects become more common. Ever higher levels of inputs—fertilizers, irrigation water, pesticides, and machinery—are required to maintain yields in the face of organic matter depletion. But if attention is paid to proper organic matter management, the soil can support a good crop without the need for expensive fixes.”
In addition to the mentioned ion uptake from compost decomposition, it has been found that rice, barley and corn can, take up an appreciable level of carbon and nitrogen from (for example) cattle manure compost through their roots[x]. I presume

the same holds for many more crops and many other organic matter supplies (cover crops, plant composts, mulches and the like).
N-fixation by leguminous crops and various soil micro-organisms delivers N in a carbon context, just like manure from ruminants does. The C content of that manure obviously depends on the fodder's C content.
No need to stress that organic agriculture basically goes for soil building. Here I just refer to some additional literature on its crop rotation and mixed farming systems[xi].

Agriculture and plant nutrition

The more we are aware of the plant's root systems' intelligent[xii] activities regarding nutrient uptake as needed then and there, the better we can adapt our plant nutrition policy. The root systems multi-functionality invites us to provide them with a soil ecosystem wherein they can find what they need when they need it. And if the soil lacks ecosystem qualities and components, such as: structure, water reserves, bacteria, mycorrhiza, minerals or whatever, the challenge is to start growing crops that provide for what is missing. Thereby feeding the soils with manures can support them in feeding the crops. In that whole process, that still is largely unknown in detail, various species of bacteria, protozoa, fungi, algae, actinomycetes and cyanobateria are involved in symbiotic recycling of micro and macromolecules[xiii]. In rain-fed areas, earthworms can figure as symbolic representatives of that whole complex soil-life system, but in worm-less dry land areas there still is considerable soil life in root zones[xiv].
Apart from feeding, plants roots can specialise in water uptake, in weathering rocks and in stabilising the plants' stems vertical uprising. And always, dying roots leave organic matter in the soils they have grown in: energy-food for the ecosystem.
Key notion here is that over-feeding crops with soluble chemicals tends to enhance not only their growth but also their susceptibility to pests and diseases while lowering their quality, especially their content of secondary metabolites that are decisive for their and our health, as well as for their flavours.

Composting for feeding soils

Apart from plant residues and animal manure left on fields, a lot of nutritious materials are centralised in stables as fodder or bedding material (straw).
Plant material shredded in the field can be left as a mulch to be brought into the soil by earthworms and decomposition by soil microorganisms.
On the farm, animal manure can be mixed with plant materials (straw) in the stable or after clearing the dung and mixing with straw in building of the dung heap[xv]. "I don't make compost because it makes me feel good. I do it because composting is the only thing I've seen in farming that costs less, saves time, produces higher yields and saves me money." is nice no-nonsense quote from a West Virginian farmer in Magdoff and Van Es' above mentioned book on Sustainable Soil Management.

In organic and biodynamic agriculture, the art of composting is highly appreciated, in various dimensions of sustainable and ethical recycling and upgrading of farm materials[xvi].

Agriculture on a systems level

As feeding the soil ecosystem with organics (‘carbon’) is a key to sustainable agriculture, it is obvious that not only one single crop or animal production, but the complete farming system is at stake[xvii]. The crop production brings in the bulk of carbon compounds (solar energy fixed by photosynthesis); leguminous crops and animal production deliver nitrogen compounds in a carbon context. Some crops are more ‘giving’, others take more than they give (potatoes, sugar beets, corns). The art of farming is to orchestrate all particular crops and animals in such a way, in space and time, that the overall effect benefits the soil fertility and human nutrition. Crop rotation (temporal variation) and mixed cropping (spatial variation) and mixed farming (plant and animal production) are tools thereto, which are particularly well developed in organic agriculture (agro-ecology, permaculture, biodynamics).
So for example a soil friendly crop rotation of 1/7th in wheat (bread), 1/7th in oil crops, 1/7th in potatoes, beetroots and vegetables and 2/7th in pulses and fodder grains would facilitate a European nutrition pattern on an on-farm fixed N ration[xviii].
Moreover, much research on the fine-tuning of mixed farming systems in various climates has been published over recent years[xix].

Agriculture and human health

A recent meta analysis[xx](2016) of 343 previous studies finds organic milk and meat to contain ca 50% more beneficial omega-3 fatty acids than their non-organic equivalent. This also applies to organic dairy products like butter, cream, cheese and yoghurt. Thus they appear to be nutritionally superior to the dairy from conventional agriculture.
Further key findings are:
- organic meat had slightly lower concentrations of two saturated fats linked to heart disease
- organic milk and dairy contains 40% more conjugated linoleic acid (CLA) – CLA has been linked to a range of health benefits including reduced risk of cardiovascular disease, certain cancers and obesity, but evidence is mainly from animal studies
- organic milk and dairy contains slightly higher concentrations of iron, Vitamin E and some carotenoids
- organic milk contains less iodine than non-organic milk (an issue which organic farmers have started to address with mineral supplements).

Another survey states that the benefits of organic products are[xxi]:

- higher levels of vitamin C, iron, magnesium, and phosphorous than nonorganic foods of the same type
- higher levels of antioxidants, naturally occurring compounds associated with a reduced risk of chronic diseases and certain cancers
- fewer toxic chemicals such as nitrates and pesticide residues
- no genetically modified organisms (GMOs)

Obviously both studies comply by and large.
Especially for vulnerable consumers, like children and pregnant woman, organic food is recommended, as Benbrook[xxii] states in his an assessment of data sets based on the known toxicity of residues. He finds a 94% reduction in health risk from regular agriculture's pesticides among those who eat organic foods.

Production capacity of 'soil building' (organic etc.) agro-ecology

In 2015 FAO's Deputy Director-General Maria Helena Semedo warns that agriculture is discovered as a big threat in the fight against climate change[xxiii]. She calls upon governments to integrate this sector into their urgent climate policies. If they fail to do so, for example because they see it as a threat for standing positions, she predicts ever more hungry people in the world. Agriculture and the good, carbon enriching use of soils, thus have made a strong debut to the series of measures against greenhouse gases, the sources of global warming. From the 186 countries that have already laid out voluntary plans to reduce their emissions, around 100 of them include measures related to the use of soils and agriculture. But Semedo warns that those measure must be effectively implemented, not stay paper on shelves.

A recent meta-analyses on the productivity of organic versus non-organic agriculture states that, with appropriate crop rotations and multi-cropping systems, organic (soil building) agriculture produces only 8-10% less as compared to non-organic (soil eroding) agriculture[xxiv]. Moreover, the various types of organic agriculture all contribute, in one way or another, to a striking decrease of the externalised problems that conventional agriculture confronts society with, now and in the future. So for example, besides the soil erosion and land degradation, there is the loss of biodiversity, the eutrophication and oceanic dead zones, the pesticide effects on humans, environment and wildlife, the greenhouse gas emissions, and the regime shifts in hydrological cycling (drought). All this the more so when forestry effects are included in (added to) those of agriculture.

Solving the global hunger problem – can organic agriculture feed the world?

In a fairly recent study, Ponisio et al (2014) concluded "As others have pointed out, agricultural yields, in and of themselves, are not sufficient to address the twin crises of hunger and obesity, both associated with poverty, that are seen in the world today. Current global caloric production greatly exceeds that needed to supply the world's population, yet social, political and economic factors prevent many people from accessing sufficient food for a healthy life[xxv]. A focus solely on increased yields will not solve the problem of world hunger. Increased production is, however, critical for meeting the economic needs of poor farmers who make up the largest portion of the world's chronically hungry people[xxvi], and agroecological methods provide low-cost methods for doing so[xxvii]. Further, environmentally sustainable, resilient production systems will become an increasingly urgent necessity in a world where many planetary boundaries have already been reached or exceeded[xxviii]. We believe it is time to invest in analytically rigorous, agroecological and socio-economic research oriented at eliminating yield gaps between sustainable and conventional agriculture (when they occur), identifying barriers to adoption of sustainable techniques and improving livelihoods of the rural poor." Their conclusion is quite in line with my findings and experiences over the past decades. Not the production is the hunger problem, it is the food's socio-economic distribution (poor people get less food) and losses in the technical distribution of food crops. The latter stands for over 100 kg/pp in the NW countries and some 10 kg/pp in poor countries[xxix]. See also the alarming Rockefeller report 'Waste and spoilage in the food chain' 2013[xxx].

This report nicely fits the 2014 request of the UN Human Rights Council for a fairer food distribution based on a regional and sustainable agriculture[xxxi].

It states that "In sum, we have entered a new century, and the questions we face now are different from those of fifty years ago. A new paradigm focused on well-being, resilience and sustainability must be designed to replace the 'productivist' paradigm and thus better support the full realization of the right to adequate food. The equation is complex, but it is one that can be solved.

Therefore multiple food systems must be combined to improve resilience through enhanced diversity, and different forms of farming must be allowed to coexist, each fulfilling a different function. The example of Brazil shows how this can be fairly well and multi beneficially realised." This well documented UN report says, In other words: we can feed the world with organic types of agro-ecological agriculture if we shift political efforts in favour of agro-ecological, labour intensive, poverty reducing forms agriculture. Then we can achieve socially appropriate 'fair' distribution of the available food, now and in the future, using environmentally and climatologically resilient, soil-building types of agriculture.

Similar results are published by Brian Halweil form the Worldwatch Institute: Can Organic Farming Feed Us All?[xxxii]. In an important sidebar he states: "Looking at 77 studies from the temperate areas and tropics, the Michigan team found that greater use of nitrogen-fixing crops in the world's major agricultural regions could result in 58 million metric tons more nitrogen than the amount of synthetic nitrogen currently used every year. Research at the Rodale Institute in Pennsylvania showed that red clover used as a winter cover in an oat/wheat-corn-soy rotation, with no additional fertilizer inputs, achieved yields comparable to those in conventional control fields. Even in arid and semi-arid tropical regions like East Africa, where water availability is limited between periods of crop production, drought-resistant green manures such as pigeon peas or groundnuts could be used to fix nitrogen. In Washington State, organic wheat growers have matched their non-organic neighbour's wheat yields using the same field pea rotation for nitrogen. In Kenya, farmers using leguminous tree crops have doubled or tripled corn yields as well as suppressing certain stubborn weeds and generating additional animal fodder."

In 2011 the Rodale institute published already similar results[xxxiii].

A year later, Scientific American's Stephen Bielo published a survey with that agreed with Rodale's earlier, and the other before mentioned publications[xxxiv].

To end this section I mention Olivier de Schutter, who most recently, in the framework of the International Framework of Experts on Sustainable Food Systems (iPES Food), presented a study advocating "A paradigm shift from industrial agriculture to diversified agro-ecological systems[xxxv]".

I quote their key messages, that nicely cover the before said in this section:

- Today's food and farming systems have succeeded in supplying large volumes of foods to global markets, but are generating negative outcomes on multiple fronts: wide spread degradation of land, water and ecosystems; high GHG emissions; biodiversity losses; persistent hunger and micro-nutrient deficiencies alongside the rapid rise of obesity and diet-related diseases; and livelihood stresses for farmers around the world.
- Many of these problems are linked specifically to 'industrial agriculture': the input-intensive crop monocultures and industrial-scale feedlots that now dominate farming landscapes. The uniformity at the heart of these systems, and their reliance on chemical fertilizers, pesticides and preventive use of antibiotics, leads systematically to negative outcomes and vulnerabilities.
- Industrial agriculture and the 'industrial food systems' that have developed around it are locked in place by a series of vicious cycles. For example, the way food systems are currently structured allows value to accrue to a limited number of actors, reinforcing their economic and political power, and thus their ability to influence the governance of food systems.
- Tweaking practices can improve some of the specific outcomes of industrial agriculture, but will not provide long-term solutions to the multiple problems it generates.
- What is required is a fundamentally different model of agriculture based on diversifying farms and farming landscapes, replacing chemical inputs, optimizing biodiversity and stimulating interactions between different species, as part of holistic strategies to build long-term fertility, healthy agro-ecosystems and secure livelihoods, i.e. 'diversified agro-ecological systems'.
- There is growing evidence that these systems keep carbon in the ground, support biodiversity, rebuild soil fertility and sustain yields over time, providing a basis for secure farm livelihoods.
- Data shows that these systems can compete with industrial agriculture in terms of total outputs, performing particularly strongly under environmental stress, and delivering production increases in the places where additional food is desperately

needed. Diversified agro-ecological systems can also pave the way for diverse diets and improved health.
- Change is already happening. Industrial food systems are being challenged on multiple fronts, from new forms of cooperation and knowledge-creation to the development of new market relationships that bypass conventional retail circuits.
- Political incentives must be shifted in order for these alternatives to emerge beyond the margins. A series of modest steps can collectively shift the centre of gravity in food systems.

Concluding this paper, I recommend interested agronomists at large, to participate in the organic agriculture's research networks such as found in European Technology Platform Organics[xxxvi] and the world wide Federation of Organic Agriculture Movements (IFOAM)[xxxvii], whereof the latter in 2013 did send an IFOAM advice regarding the development of the Russian law on organic agriculture[xxxviii].

As for the research, the biggest challenge is to adapt the research methodology and technology to the multifunctional, explicitly ethical system of cyclic processes that are relevant for the individual farmer: regional and seasonal. Linear mechanisms, worthwhile as they can be, do only figure in a healthy way within the context of organically whole farming systems. Thus a transition of perceptions and models, of paradigms and belief systems may shed a new light on our common future.

The FAO's concern of 'regular' agriculture's shockingly big contribution to the soil erosion worldwide, caused that UN organisation to call the year 2015 the year of the soil[xxxix]. The fact that this science and government supported agriculture is the big soil eroding agent, clearly indicates the need for the mentioned mental transition, as well as the helpful perspectives of agro-ecological, organic, permaculture and biodynamic farming models.

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