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Objectives of plant nutrition research in organic farming

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Abstract

There is an increasing consumer demand for foodstuff which has been produced according to the EU guidelines for organic farming systems (EU guidelines (2092/91/EWG)) and it is the aim of the German government to increase the share of organic farms to 20 % within the next ten years. The most important quality aspect of organically produced crops is without doubt the lack of contamination by pesticides, but besides this nutritional, phenotypic and technological aspects are major criteria for the acceptance of the products by consumers and industry. Plant nutrition plays a key role in organic farming as a harmonic nutrition of the crop is essential not only for producing high quality feedstuff and food, but also for promoting natural plant resistance mechanisms against pests and diseases. Though nitrogen is regularly the strongest limiting growth factor in organic farming systems, other nutrients such as sulfur may also have a strong impact on crop quality. Knowledge on the spatial variability of plant available nitrogen in the soil together with variable rate application of organic fertilizers may help to compensate nitrogen limitations and to improve yield stability.

Key words: crop response curves, environment, fertilizer, quality, plant health, medical plants, precision agriculture

Zusammenfassung

Ziele der Forschung in der Pflanzenernährung im ökologischen Landbau

Es besteht eine steigende Nachfrage nach Nahrungsmitteln, die gemäß den Richtlinien der EU-Verodnung (2091/91/EWG) produziert wurden und es ist das erklärte Ziel der Bundesregierung den Anteil ökologisch bewirtschafteter Betriebe in den nächsten 10 Jahren auf 20 % zu erhöhen. Der wichtigste Aspekt ökologischer angebauter Pflanzen ist zweifelsohne die Tatsache, dass die Produkte nicht mit Pestizidrückständen belastet sind. Darüber hinaus sind für die Akzeptanz der Produkte durch Verbraucher und Industrie ernährungsphysiologische, phänotypische und technologische Aspekte wichtige Kriterien. Pflanzenernährung nimmt im ökologischen Landbau eine zentrale Rolle ein, da eine harmonische Ernährung notwendig ist, um qualitativ hochwertige Nahrungs- und Futtermittel herzustellen und die natürliche Resistenz gegenüber Schaderregern zu fördern. Obwohl Stickstoff regelmäßig am stärksten den Ertrag limitiert, können andere Nährstoffe wie Schwefel einen starken Einfluss auf die Qualität der Pflanzen nehmen. Der Engpass in der Stickstoffversorgung könnte eventuell durch Kenntnisse über die räumliche Variabilität von pflanzenverfügbarem Stickstoff im Boden und die daran angepasste variable Ausbringung organischer Düngemittel überwunden werden und dadurch zur Ertragsstabilität beitragen.

Schlüsselworte: Düngemittel, Medizinalpflanzen, Pflanzengesundheit, Precision Agriculture, Qualität, Umwelt, Wachstumskurven

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1 Introduction

Agriculture was associated positively with food production and food security less than a century ago. It is nowadays commonly linked to problems such as eutrophication of water bodies, enrichment of pesticides in soils and plants and contamination of meat with hormones. Additionally BSE (Bovine Spongiform Encephalopathy), foot and mouth disease and cropping of genetically modified plants contributed to a tremendous loss of trust in the quality of the produced foodstuff. Alternatives for consumers are products from organic farming which bans industrial nitrogen (N) fertilizers and pesticides completely and which acknowledges ethical aspects of livestock production.

Organic farming has been stirring the emotions of conventional farmers since its beginnings with the organic farming movement initiated by Sir Albert Howard (1873-1947) and the anthroposophic agricultural lectures of Rudolf Steiner in the early 1920's (Barton, 2001; Steiner, 1924). Extended investigations were carried out in order to identify qualitative differences between products from both management systems (Woese et al., 1995 and 1997) and organic products usually had a significantly higher dry matter content and lower nitrate concentrations (Woese et al., 1997). But nutritional quality implies not only physico-chemical parameters which can rapidly be determined by laboratory analysis, but also 'dynamic' features which Balzer-Graf (1987) describes as vitality, differentiation and regeneration. These can be assessed so far only by picture forming methods.

There are indications that organic food is beneficial for the human health, because organic products contain for example no potentially harmful food preservatives, pesticides and phytochemicals, but more experimental studies are required to prove this hypothesis (Marckmann, 2000). Apart from the viewpoint of quality it is the way how foodstuff is produced and animals housed that is favored by consumers.

Research in plant nutrition and soil science is not dependent on the management system and therefore universally valid. The major difference between organic and conventional farming is summarized by Schmidt and Haccius (1998): "The primary concern of organic agriculture is not the substitution of depleted nutrients and not that of feeding plants, but rather feeding soil life. Consequently an organic farmer does not aim at defined crop yields by providing for a certain input of fertilizers and nutrients." Organic farming aims at closed nutrient cycles, but an adequate supply of essential plant nutrients and organic matter is indispensable in order to maintain crop productivity and soil fertility. It has been the aim of this contribution to highlight relevant issues of plant nutrition in organic farming with view to future research needs.

2 Aspects of plant nutrition in organic farming

The plant nutrient supply affects yield, quality and natural plant health as well as the environment. The supply of plants with mineral elements has a direct impact on the content of primary and secondary compounds and their mineral composition (figure 1). The efficacy of new technologies such as precision agriculture for a site-specific, variable rate input of organic fertilizers needs to be evaluated and its profitability for organic farms experimentally proven. Nutrient induced resistance mechanisms and allelopathies may be used to develop effective countermeasures against weeds, pests and diseases. Last but not

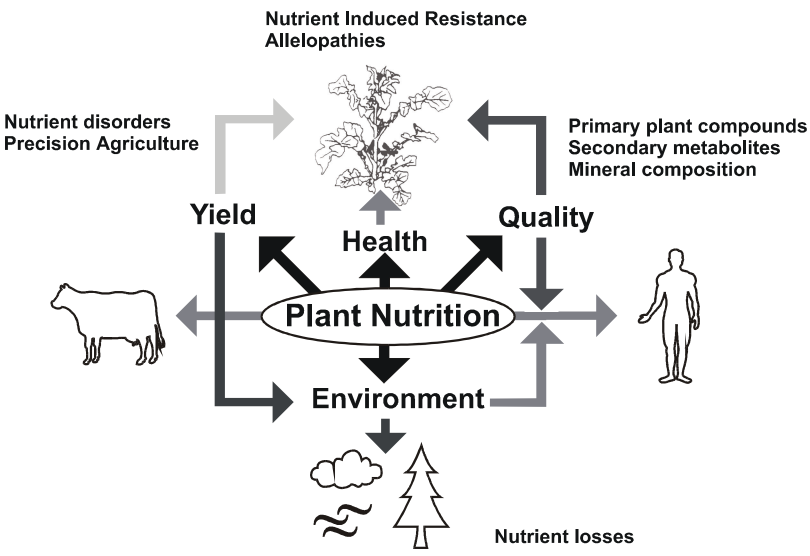

Fig. 1
Aspects of lant nutrition research in organic farming

least nutrient losses to the environment cannot be avoided, but should be minimized by appropriate agro-technical measures.

3 Nutrient supply and crop yield

3.1 Evaluation of the plant nutritional status

Liebig's "Law of the Minimum" (1855) is the basis for plant nutrition in conventional farming. It states that the exploitation of the genetically fixed yield potential of crops is limited by the variable, which is insufficiently supplied to the greatest extent. This theory neglects interactions between growth factors, but proved to be sufficiently accurate to estimate the single response of the nutrient (Lark, 2001). A quite important disadvantage of critical nutrient values or even ranges of critical values (tissue concentration for 95 % of maximum yield) (Mills and Benton Jones, 1997) or "no effect values (NEV)" (tissue concentration for maximum yield or the concentration above which yields fail to response) (Finck, 1970) is that they do not respect the non-linear "Mitscherlich" relationship between growth factors and yield (Wallace, 1990). Static critical nutrient values are not applicable in organic farming systems because the target is not a certain crop yield (see above). In comparison, symptomatological nutrient thresholds which correspond to nutrient concentrations in the plant tissue below which macroscopic deficiency symptoms become visible are for all farming systems.

Important for organic farmers is information of crop response to different levels of soil nutrients so that plant nutrients may be ranked according to their yield limiting effect. Particularly, if N is not the strongest yield limiting factor, then decisions need to be made to either correct the nutrient deficiency or to match the input of organic fertilizers with the yield level that can be achieved. In cases where the nutrient, for instance sulfur (S), has a direct impact on crop quality (see below), fertilization may be indispensable.

An approved method to determine crop response curves is the boundary line approach (Webb, 1972). Large sets of yield data are plotted against nutrient concentrations in defined plant organs which cover a wide range of growth factor combinations. The line describing the highest yields observed over the range of nutrient values measured is known as the boundary line since it lies on the upper edge of the body of the data (Webb, 1972). The boundary line describes the response to variation in the test parameter where all other factors are non-limiting in terms of crop yield. Data points below this line relate to samples where one or more other factors limit crop response to the nutrient. Thus boundary lines describe the "pure effect of a nutrient" on crop yield under "ceteris paribus" conditions (Evanylo and Sumner, 1987; Walworth et al., 1986). When upper boundary line functions are available, these may be used to calculate the yield that can be obtained at a given nutrient supply (Schnug and Haneklaus, 1998). As the upper boundary line approach is not widely used, it could be helpful to establish response curves for those nutrients and crops where such information is not available.

3.2 Nutrient disorders

At the moment N and S are supposedly the most important nutrient disorders in organic farming. N is supposedly most often limiting crop performance as the N supply is warranted more or less exclusively by farmyard manure and legumes in the crop rotation. But the amount of organic fertilizers is often limited because of low stocking densities or even missing in case of stockless farms. Research needs to focus on improving the nutrient storage capacity and on increasing the efficiency of farm inherent nutrient cycles, particularly for N and P.

The proportion of legumes in mixtures of forage legumes and grasses strongly influences yield and quality of the harvest product (Heuwinkel and Locher, 2000). The plant available N content in the soil is one important factor influencing the N_2 fixation of legumes (Hansen and Vinther, 2001) and high levels are known to lower the proportion of N derived from the atmosphere by clover and reduce its yield, while that of grasses is promoted (Hogh-Jensen and Schjoerring, 1994). Plant available N contents in the soil show a high spatial and temporal variability, particularly on grazed grassland due to urine and dung patches (Afzal and Adams, 1992; Lantinga et al., 1987). Besides this, climatic conditions such as temperature influence N fixation of legumes. At low temperatures clover relies stronger on mineral soil N (Nesheim and Boller, 1991). This means that innovative approaches such as remote sensing techniques could be employed to determine the legume:gras ratio and crop yield, and that this information could be used to estimate N fixation (Heuwinkel and Locher, 2000), and to develop site-specific strategies for seed mixtures and the management of resources. In this context the question is admissible whether 'high-tech' concepts such as precision agriculture are in line with organic farming (Solemdal, 2000). Precision agriculture technologies are suitable as long as they do not interfere with social conditions, e.g. substituting labor by machines, human needs, e.g. replacing the know-how of the farmer by farm management models and ecological aspects, e.g. interfering with soil fauna and flora. Then they might offer the opportunity to optimize plant production in organic farming, for instance by developing site-specific strategies for forage mixtures (see above) or by applying mineral fertilizers and farmyard manure spatially variable.

Severe S deficiency is meanwhile a major nutrient disorder in northern Europe and gains increasing relevance in organic farming. Haglund et al. (2000) and Hagel (2000a) showed yield and quality of crops was limited by S. As organic fertilizers provide only a limited amount of S with an average of 0.07 kg S per kg of N and S mineralization is usually low, S fertilization may be the only way to warrant crop productivity in rural areas with low atmospheric S deposition. Under humid conditions leaching of sulfate over winter is the major reason for S losses from the rooted soil layers. S losses can only be reduced in so far as biomass production before winter and root development of the crop is promoted. So far no data exists concerning the influence of the S supply on N_2 fixation of legumes (Haglund et al., 2001).

3.3 Local Resource Management of agricultural soils

Local Resource Management (LRM) is the conceptual idea of matching agricultural inputs and operations with the spatial distribution of qualitative and quantitative features of natural resources (Schnug et al., 1993). A site-specific nutrient management of organic fertilizers is supposed to improve the N utilization efficiency and thus crop productivity (see above; Haneklaus and Schnug, 2002).

Even if no organic fertilizers are available, for example on stockless farms, the site-specific management of soil borne nutrients may be an intriguing approach. The strategy would then be to apply spatially variable measures, which increase the utilization of soil nutrients. Increasing their mobility or uptake efficiency of the crop could do this. The first option would be feasible for nutrients with an expressed dependency on soil pH such as micronutrients and P (Schnug, 1992; Schnug and Finck, 1982), the second by promoting root growth in order to improve the source:sink ratio of nutrients. A site-specific nutrient management for liming is generally acknowledged as important, because pH is highly variable in soils (Bongiovanni and Loewenberg-Deboer, 2000; Heiniger and Meijer, 2000). The soil pH is one of the most important factors influencing the mobility of soil nutrients (Schnug, 1982) and variable rate liming can be an effective and profitable way to optimize the nutrient supply (Parkhomenko et al., 2002).

The Council Directive 79/117/EEC states among others that plant protection products aim at destroying undesired plants and to destroy parts of plants or to prevent undesired growth of plants. An innovative challenge for weed control is the concept of Nutrient Induced Competition (NIC): the basic idea is to apply strongly concentrated nutrient solutions specifically to weeds. This causes physiological disorders and will kill or at least reduce the vigor of the weed plant. This again enhances the relative competitiveness of the crop plant. Technically this would employ sprayers with opto-electronic control systems, which are able to differentiate between weed and crop plant (Biller et al., 1997). Suitable nutrient solutions may contain KCl and NaCl, respectively. An indispensable condition is that the selective treatment of the weed plants will not yield an undesired enrichment of nutrients in the soil. Research is required to determine the dose response relationships of different salt concentrations and the entailed nutrient input, to test these salt solutions at different growth stages of the weed plants and to study the susceptibility of different weed species.

3.4 Fertilizers for organic farming

In organic farming systems the use of processed N and P fertilizers is prohibited with the exception of basic slag. In general, the need of a certain mineral or organic fertilizer product needs to be recognized by the inspection body or inspection authority. Approved fertilizers for organic farming in Europe are listed in table 1. Differences between countries may exist and are listed by Schmidt and Haccius (1998).

In case of N, legumes and farmyard manure cover the demand of the crop, while P needs to be replaced by mineral amendments. As rock phosphates have only a very limited solubility in soils it can be expected that P is or will become a minimum factor, particularly on poor soils, and heavy soils after long-term conversion to organic farming. A solution to the solubility problem could be the application of an elemental S/rock phosphate product. The hypothesis is that elemental S causes a local soil acidification which dissolves the fine-ground rock phosphate and thus enhances the amount of plant available phosphorus.

4 Nutrient supply and crop quality

4.1 Non-protein nitrogen compounds

The enrichment of non-protein N compounds such as amides is primarily a problem of an excess N supply, and is promoted if S deficiency occurs at the same time. Amides are known to cause an unpleasant off-flavor in vegetables. The most important non-protein N compound enriched following S deficiency is nitrate. Nitrate is prone to microbiologically induced reduction to nitrite by nitrate reductase during storage and processing of vegetables and nitrite is toxic to humans by blocking the oxygen carrying capacity of haemoglobin or as a potential precursor for carcinogenic nitrosamines.

Infantile methaemoglobinaemia, the last reported case was in 1972 (Schlatter, 1984), has meanwhile proved to be induced by bacterial infections in combination with an increased nitrate uptake which enforces oxidation of haemoglobin to methaemoglobin as infants have lower

Table 1
Approved products for fertilization in organic farming systems (FIBL, 2001)

	Composition[1]
75-85 % OMC[2]; 9-14 % N	*Solid N-rich products:* [3]bone meal, [3]blood meal; compost; [3]horn meal; feather meal; sugar cane molasses; stillage; sugar molasses; [3]horn; [3]claws
9.5 % N	*Liquid N-rich products:* vinasse
2.6-13 % P	*P-rich products:* basic slag (Thomas-phosphate); [4]raw phosphate; [5]calcinated aluminium phosphate rock; [2]mammal bones; [2]bone meal;
9-42 % 13-98 % S	*K-rich products:* potassium sulphate; kainite (potassium raw salt) S-rich products:potassium sulphate; kieserite; epsom salt; gypsum; elemental S
21-36 % Ca; 0.1-11 % Mg	*Liming products:* dolomite ($CaMg(CO_3)_2$); chalk ($CaCO_3$)

note: all products are conform with organic farming guidelines whereby the efficiency of the product is not necessary for approval; [1]either mono or multi-component products; [2]OMC organic matter content; [3]trading and use forbidden; [4]maximum Cd content: 39 mg Cd per kg P; [5]only on soils with pH >7.5

concentration of acid in their stomachs than adults so that there are more nitrate reducing bacteria (Leifert and Golden, 2001).

There is a still ongoing discussion whether an increased intake of nitrate enhances or reduces the risk of gastrointestinal cancer. Leifert and Golden (2001) attribute a reducing effect to the fact that nitrate is reduced in the oral cavity to nitrite which is protective against intestinal pathogens. In contrast Schlatter (1984) found a close relationship between nitrate intake and nitrite synthesis in the oral cavity and stated that the synthesis of nitrosamines increased over-proportional with increasing nitrate and nitrite intake. In contrast Ellen et al. (1982) found no formation of nitrosamines in humans after intake of nitrates. Nitrosamines are carcinogen and mutagenous (Hodgson and Levi, 1997). An intake of 0.17 mg nitrate per kg body weight yields a spontaneous mutation rate of 12.5 % (Wiesner, 1984).

4.2 Baking quality of wheat

An insufficient S supply will reduce the baking quality of wheat (Haneklaus et al., 1992; Haneklaus and Schnug, 1992). Resistance against extensibility is increased in S deficient wheat (Wrigley et al., 1984). Relevant in this context is that modern winter wheat cultivars were bred for high input systems. As doughs were too soft in the past, the baking quality was improved by increasing the proportion of the glutenin content (Hagel 2000b). Under conditions of S deficiency the doughs of these varieties turned out to be too tough and thus reducing the baking quality. As these limitations can be balanced by S fertilization (Hagel 2000a; Haneklaus et al., 1992) this implies that modern cultivars are physiologically S deficient and Hagel (2001) raises the question whether this is acceptable for organic growers and their concepts of quality of nutrition.

4.3 Organoleptic characteristics

Rembialkowska (2000) states that particularly fresh organic vegetables had significantly better sensory features (taste, odor) than conventional products. Marckmann (2000) expects a higher intake of organic food because of favorable sensory features which in return may positively affect diseases such as obesity and type 2 diabetes. It is known that organoleptic features of vegetables are linked to nutritional factors: glucosinolates and alliins cause for instance the pungency of mustard, radish, onion and garlic. Both components contain S and experimentation proved that their content could be increased significantly by S fertilization. Besides that glucosinolates are supposed to have a high health protective effect which reduces the risk of cancer and alliins act anti-biotic (Bloem et al., 2001a).

4.4 Medical plants

There are many plants with therapeutically active compounds claiming to act as anticarcinogenic, antibiotic, antihypertensive and cholesterol reducing agents (Verhoeven et al. 1997). There is an increasing market for phytopharmaceuticals (Bomme, 1998) and such products are of interest for human and animal application. The latter aspect is of prime interest as medicinal substances are banned in organic farming and infectious diseases of the gastrointestinal tract a severe problem (Jacobsen and Hermansen, 2001). The validation of the curative effect of different medical plants is important for developing new, efficient phyto-pharmaceuticals.

The cropping of medicinal plants could positively contribute to the income of organic farms as the guidelines for good agricultural practice for medicinal and spice plants demands products which are not contaminated by pesticides (Europam, 1998). The requirements with view to homogeneity and quality, particularly the content of bioactive components are continuously increasing so that adequate crop-specific growth conditions need to be elaborated. Growth conditions such as temperature, light intensity and species (Rosa and Rodrigues, 1998), nutritional factors like for instance the S supply strongly influence the content of bio-active components (Bloem et al., 2001a and 2001b) and research needs to be carried out for fertilizer recommendations in organic farming which meet market requests.

4.5 Quality assessment

The elaboration of methods which proof the origin of an agricultural product is necessary in order to control and prevent a misuse of the label organic. The bio-photon analysis was developed by Popp (2000) and is based on the measurement of a weak emission of light in the spectral range of 200-800 nm from biological and organic systems. The measurement of light emissions after an adoption phase under dark conditions and/or defined excitation is a sensitive procedure to characterize foodstuff quality. A major problem, however, is to set qualitative differences in relation to causal factors (Popp, 2000). It is the aim of picture forming methods to overcome this difficulty. Picture forming methods (PFMs) as for instance capillary dynamolysis are usually applied for the quality assessment of products in organic farming, e.g. the supervision of crop quality in different growing systems and the characterization of different cultivars (Balzer-Graf, 1987 and 2000). Tingstad (2000) demands both, a technical validation and a validation of possible correlations of capillary dynamolysis with other methods so that the information that is provided by these methods is no longer dependent on specialized experts, but can be assessed universally. Here, the use of image processing for the interpretation of pictures could be a promising approach in order to standardize the procedure.

5 Nutrient supply and natural plant health

5.1 Nutrient Induced Resistance (NIR)

Since plants and pathogens have coevolved, both have developed efficient strategies for survival. Plants have developed different forms of resistance. Nutrient induced resistance was observed for phosphate (Reuveni et al., 1994; Walters and Murray, 1992), silicone (Chérif et al., 1993) and sulphur (Bourbos et al., 2000; Schnug et al., 1995). The concept of Sulphur Induced Resistance (SIR) aims to stimulate the metabolic pathways involved which include an increased synthesis of natural components (e.g. H_2S, glutathione), the degradation of glycosides (e.g. glucosinolates), the synthesis of new components (e.g. phytoalexins), the hypersensitive response and deposition of elemental S (Haneklaus et al., 2001).

Plants take up silicone and a thin layer of silicic acid can be found between cell wall and cuticle. Yoshida et al. (1969) attributed an improved tolerance of plants against pests and diseases to this cutin-silicic acid layer. In comparison, foliar applications of water glass change the pH of the leaf surface and by this mechanism supposedly impede fungal infestations.

The identification of different mechanisms of nutrient induced resistance and the creation of a micro-climate on the leaf surface which hampers the infestation with pathogens may significantly contribute to develop natural plant protection measures.

5.2 Allelopathy

Allelopathic effects could be used in organic farming for pest and weed control (Mazzola et al., 2001; Thaning and Gerhardson, 2001; Petersen et al., 2001). Glucosinolate hydrolysis metabolites have a broad spectrum of biological activity and research focuses on the use of plant residues or application of seed meal against fungal diseases and nematodes (Mazzola et al., 2001; Angus et al, 1994; Ramirez-Villapudua and Munnecke, 1988; Thaning and Gerhardson, 2001). Particularly small seeds of weeds proofed to be sensitive against isothiocyanates released from turnip mulch (Petersen et al., 2001). Nevertheless, more research is required with view to a practical use of these findings.

6 Nutrient supply and environment

Generally it is not possible to exclude nutrient losses to the environment on agricultural fields, but acceptable loads need to be defined as for instance excess N in the environment causes eutrophication of water bodies and release of climatically relevant trace gases. Though the N flow is lower in organic farming, this will not yield ‘per se’ lower rates of nitrate leaching (Kirchmann and

Bergstroem, 2001). In fact the amount and timing of N fertilization, crop type and crop rotation play a key role for N losses by leaching in organic and conventional farming (Kirchmann and Bergstroem, 2001; Weisskopf et al., 2000). Relevant for the N fertilizer efficiency is a sufficient supply with other plant nutrients. S, K, Mg, Zn, Cu and B deficiency may result in a real N fertilizer efficiency of 19-32 % compared to 74 % under optimum conditions (Schnug, 1991).

A quantitative limitation of N fertilization will not reduce non-point N losses effectively, because of the phenomenon of the spatial variability of soil features affecting nutrient utilization. The average nutrient surplus of a field is the result of a greater number of individual events which in the case of N can easily vary by 100 % from the average. It is therefore not satisfying to define "the field" as the smallest operational unit for applying balanced fertilization. The smallest operational unit should be the pedon which represents the smallest homogenous unit or area in a field in terms of soil factors influencing nutrient dynamics and soil classification features. The size of a pedon depends on the landscape. A site-specific, variable rate nutrient management could therefore be the solution to this universal problem (see above).

7 Conclusions

The results reveal that aspects of plant nutrition in organic farming will gain increasing interest and concern, respectively. Crop quality and promotion of natural plant health by nutrient induced resistance mechanisms are supposed to be of major relevance for organic farmers. The efficacy of precision agriculture technologies to improve the N supply and to reduce N losses to the environment needs to be verified under practical conditions.

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