ORGANIC PLANT PRODUCTION - LIMITED BY NUTRIENT SUPPLY? AN OVERVIEW

H.M. Paulsen[1], S. Haneklaus[2], G. Rahmann[1] and E. Schnug[2]

[1]Institute of Organic Farming, Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI), Trenthorst 32, 23847 Westerau, Germany, hans.paulsen@vti.bund.de, phone +49 4539 8880 316

[2]Institute for Crop and Soil Science, Federal Research Center for Cultivated Plants (JKI), Bundesallee 50, 38116 Braunschweig, Germany,
e-mail: silvia.haneklaus@jki.bund.de, phone +49 531 596 2101

Abstract

In organic plant production the number of approved mineral fertilisers is strictly limited. Additionally, various by-products and residues from industrial processes, mainly from the food industry can be used for fertilisation. The early organic farming movement in the 20th century used household-composts and sewage sludge, but the awareness of the existence of organic and inorganic xenobiotics in those products excludes nowadays categorically nutrient recycling. The vitality of organic plant production is mainly based on farmyard manure and legume growth. Organic farming aims at closed nutrient cycles despite the risk of negative nutrient balances and nutrient mining. Nevertheless the productivity level in organic farming is constant since many years. Residues from local bio-energy production on the basis of organically grown crops could be the key to break up mental reservations against fertilisation with externally recycled materials as the concept is in agreement with legitimate organic directives. Biogas residues from fallow-legumes offer for instance a new tool to optimise N-fertilisation on organic farms and could increase productivity substantially. Other options to improve nutrient management on organic farms comprise nutrient mobilisation in the soil by roots and/or mycorrhiza, improved nutrient uptake and utilisation efficiency of plants by breeding and the recycling of environmentally sound waste-materials.

Keywords: biological nutrient mobilisation, organic farming, macronutrients, micronutrients, farm residues, biogas slurry, waste recycling.

Introduction

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. 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 plant production relies on internal nutrient cycling and on the application of nutrients with organic materials from organic production. With the introduction of mineral fertilisation mid of the last century crop yields increased rapidly in conventional agriculture. In comparison, crop productivity in organic farming relies on a high soil organic matter and soil N content and the conservation of soil water resources so that organic farming may have special advantages under drought conditions (Pimentel *et al.*, 2005) and may contribute to food security in regions, which rely on local farming systems (Badgley *et al.*, 2007; Scialabba, 2007; Scialabba and Hattam, 2002). In contrast, in industrial countries with favourable cropping conditions, high input of resources and crop rotations that are limited by strong market interactions an improved nutrient management is the key to raise yields in organic farming and to secure further yield benefit from future technical-biological developments. For the application of external fertilizers the regulations of organic farming laws on fertiliser use in different countries and special guidelines of different growers associations have to be taken into account. In Europe the EC-Council Regulation No EU 834/2007 is the minimum basis for organic production. Accredited fertilisers are generally listed in the Commission Regulation No EU 889/2008. Trade names and products are published in special lists like the German 'Betriebsmittelliste' (www.FiBL.org) or the US 'National List of Allowed and Prohibited Substances' (www.ams.usda.gov). In this paper current knowledge on nutrient limitations and possibilities to maintain and improve plant nutrient supply in organic production are discussed.

Results and Discussion

<u>Macronutrients</u>

Nitrogen (N) is regularly the strongest limiting growth factor in organic farming systems. The use of mineral N fertilisers is prohibited in organic farming. The N supply is mainly covered by rhizobial N from legume cultivation (Peoples *et al.*, 2009). By-products of animal or vegetable origin (horn meal, feather meal, extracted oilseed rape meal, legume seed meal, molasses, vinasses) are frequently used in organic vegetable production to compensate an insufficient N supply (Laber, 2009; Mueller *et al.*, 2007). Cropping systems relying on organic N import, which is a common problem in arable vegetable production (Koller and Lichtenhahn, 2004) run contrary to the directives of organic farming, which unambiguously demand closed nutrient cycles. In this context Haneklaus *et al.* (2005) described particular methods of soil analysis for organic farming, which comprise structural and biological soil parameters to evaluate the soil fertility status. The necessity of humus and nutrient recycling from by-products of the food chain was already accentuated in the early days of the organic movement (Rusch, 1964; Sir Albert Howard, 1943). Nowadays the use of household wastes and sludge on agricultural land is excluded for basic reasons of hygiene and contamination with organic (such as pharmaceutical residues) and inorganic (heavy metals) xenobiotics. The development of a complete extraction of all xenobiotics would be necessary before restarting a discussion on their use in organic farming (Rahmann *et al.*, 2009; Gethke *et al.*, 2008). The use of materials produced on an organic farm, particularly its by-products was emphasized by Sir Albert Howard (Sir Albert Howard and Wad, 1941) and an increased use of biomass for bio-energy production might deliver residual products which provide the minimum key nutrient N (Moller *et al.*, 2008, Stinner at al. 2008). Thus organic farmers may intensify productivity of cash crops without compromising the primary ideal of organic farming.

In contrast to N, for all other essential plant nutrients the off-take by harvest products is higher than the input. Nutrient balances are required for keeping a balanced nutrient input (Watson *et al.*, 2002). But threshold values available for crops produced on conventional farms (Barker and Pilbeam, 2006) have not been validated for organic farming. Static critical nutrient values are not applicable in organic farming systems because the target is not a targeted crop yield. Interactions between growth factors need to be taken into account site-specifically. An appropriate approach to interpret results and derive critical nutrient values for soils and plants is provided for instance by the BOundary LIne DEvelopment System BOLIDES (Schnug and Haneklaus, 2008). So far, lower soil nutrient levels are supposed to be sufficient because of the lower nutrient demand of crops for a reduced yield level (Kolbe, 2001). Such approach, however, does not live up to the basic ideas of organic farming. It will be necessary to compare separately critical nutrient values for different organic faming systems and on arable and livestock farms.

The K supply on organic farms may be marginal or insufficient on coarse structured soils (Oborn *et al.*, 2005; Askegaard *et al.*, 2003). Here, deficiencies can easily be compensated with K salts. In case of S (Paulsen, 2005) and Mg deficiencies natural gypsum, kieserite and Mg or S containing limestone can be used.

Looking at the limited world phosphate (P) reserves an efficient recycling of residual P from industries, households and incineration of biomass is inevitable (Schnug *et al.*, 2003). There are consistent results that organic farming takes advantage of soil P levels from former (conventional) fertilisation (Van Den Bossche *et al.*, 2005; Oehl *et al.*, 2002; Loes and Ogaard, 2001). The application of raw phosphates is not adequate to satisfy the P demand of crops because of their insufficient solubility. A sustainable use of P in organic farming requires a substantial improvement of the solubility of rock phosphates and bone meals as otherwise this non-renewable resource is deposited in a non-accessible form for plants in soils. The result: plant available soil P levels will decrease and soil fertility will diminish. An *in situ* digestion with a combination product of elemental S and rock phosphate enhanced significantly the solubility of non water-soluble P sources (Schnug and Haneklaus, 2006). Other options to improve P uptake is mobilisation by mycorrhiza (Kahiluoto and Vestberg, 1998) and P-efficient plants, which are able to explore P reserves by high root density or root exudates (Eichler-Lobermann *et al.*, 2008).

Micronutrients

Usually an insufficient supply with micronutrients is a problem of limited plant availability and not a limited reserve. In general, adjustment of the soil pH by liming will ensure a sufficient supply with micronutrients.

The application of organic manures or composts increases the micronutrient supply (Mn, Zn, Cu) (Herencia *et al.*, 2008). Studies on microelement concentrations in herbage indicated that Cu, Mo, Co, Zn, Fe or Mn were not limiting plant growth in organic herbage production (Govasmark *et al.*, 2005a; Govasmark *et al.*, 2005b). A higher mycorrhizal colonization of roots because of a lower P supply in organic systems may yield higher Zn concentrations when compared to conventional wheat grain (Ryan *et al.*, 2004). Another external source of micronutrients are feed additives. Mineral feed additives may charge soils with micronutrient loads (Cu), which needs to be evaluated critically (Gustafson *et al.*, 2007; Linden *et al.*, 2001; Olsson *et al.*, 2001). Heavy metal contents (Cd, Pb, Hg, As) and other undesirable substances in animal feed are limited in the Directive 2002/32/EC. Particularly phosphates may contain considerable amounts of undesired elements (Sullivan *et al.*, 1994). The Cd content in fertilisers is regulated to a maximum of 90 mg kg^{-1} P_2O_5 (EC 889/2008), but lower values are discussed and part of the fertiliser directives of some EU Members states (e. g. Germany 60, Finland 50 mg Cd kg^{-1} P_2O_5). So far no thresholds exists for U in fertilisers and feed additives (Knolle *et al.*, 2008; Uberschar, 2006). U is a toxic heavy metal and anthropogenic U contamination of agricultural soils is closely related to nationwide fertilization practices. The U content in rock phosphates may be as high as 220 mg kg^{-1} U. Particularly P fertilizers are known to add significant U loads to soils (Schnug and De Kok, 2008).

The results clearly reveal research deficits in the field of development of methods and criteria for evaluating nutrient availability and nutrient supply, and fertiliser demand in organic farming. In addition organic farming requires not only innovative approaches to improve nutrient availability as it was shown exemplary for P, but also regulatory updates of fertiliser regulations concerning environmentally relevant elements such as U.

References

Askegaard, M., Eriksen, J. and Olesen, J.E., 2003: Exchangeable potassium and potassium balances in organic crop rotations on a coarse sand. Soil Use and Management 19(2):96-103

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Viles-Vazquez, K., Samulon, A. and Perfecto, I., 2007: Organic agriculture and the global food supply. Renewable Agriculture and Food Systems 22(2):86-108

Barker, A.J. and Pilbeam, D.J., (eds) 2006: Handbook of plant nutrition. Boca Raton : CRC Press

Eichler-Lobermann, B., Kohne, S., Kowalski, B. and Schnug, E., 2008: Effect of catch cropping on phosphorus bioavailability in comparison to organic and inorganic fertilization. Journal of Plant Nutrition 31(4):659-676

Gethke, K., Montag, D., Herbst, H. and Pinnekamp J., 2008: Phosphorrückgewinnung aus Klärschlamm. In: Müllhandbuch ; Lfg 2/08. Erich Schmid Verlag.

Govasmark, E., Steen, A., Bakken, A.K., Strom, T. and Hansen, S.; 2005a: Factors affecting the concentration of Zn, Fe and Mn in herbage from organic farms and in relation to dietary requirements of ruminants. Acta Agriculturae Scandinavica Section B-Soil and Plant Science 55(2):131-142.

Govasmark, E., Steen, A., Bakken, A.K., Strom, T., Hansen, S. and Bernhoft, A., 2005b: Copper, molybdenum and cobalt in herbage and ruminants from organic farms in Norway. Acta Agriculturae Scandinavica Section A-Animal Science 55(1):21-30.

Gustafson, G.A., Salomon, E. and Jonsson, S., 2007: Barn balance calculations of Ca, Cu, K, Mg, Mn, N, P, S and Zn in a conventional and organic dairy farm in Sweden. Agriculture Ecosystems & Environment 119(1-2):160-170.

Haneklaus, S., Schnug, E., Paulsen, H.M. and Hagel, I., 2005: Soil analysis for organic farming. Communications in Soil Science and Plant Analysis 36(1-3):65-79.

Herencia, J.F., Ruiz, J.C., Melero, S., Galavis, P.A.G. and Maqueda, C., 2008: A short-term comparison of organic v. conventional agriculture in a silty loam soil using two organic amendments. Journal of Agricultural Science 146:677-687.

Kahiluoto, H. and Vestberg, M., 1998: The effect of arbuscular mycorrhiza on biomass production and phosphorus uptake from sparingly soluble sources by leek (Allium porrum L.) in Finnish field soils. Biological Agriculture & Horticulture 16(1):65-85.

Knolle, F., Haneklaus, S. and Schnug, E., 2008: Indications for contamination of water bodies with uranium through fertilization. Proc. 17th Int. Symp. of CIEC, Cairo, Egypt, 2008, 350-356.

Kolbe, H., 2001: Instructions for phophorous, potassium, magnesium and lime fertilisation in organic agriculture. (in German). SÖL Beraterrundbrief 3:3-9.

Koller, M. and Lichtenhahn, M., 2004: Nitrogen supply in organic field vegetable production. Der Gemüsebau/ Le Maraîcher 3:27-31.

Laber, H., 2009: Model for demand-oriented N-fertilisation in organic vegetable production: Introduction into agricultural practice and evaluation. In: Anon. Dresden Pillnitz : Sächsische Landesanstalt für Landwirtschaft, pp 1-29, Bericht, Fachbereich Gartenbau und Landespflege.

Linden A, Andersson K, Oskarsson A, 2001: Cadmium in organic and conventional pig production. Archives of Environmental Contamination and Toxicology 40(3):425-431.

Loes, A.K. and Ogaard, A.F., 2001: Long-term changes in extractable soil phosphorus (P) in organic dairy farming systems. Plant and Soil 237(2):321-332.

Moller, K., Stinner, W., Deuker, A. and Leithold, G., 2008: Effects of different manuring systems with and without biogas digestion on nitrogen cycle and crop yield in mixed organic dairy farming systems. Nutrient Cycling in Agroecosystems 82(3):209-232.

Mueller, T., Riehle, J., Schlegel, I., Li, Z., von Schenk zu Schweinberg-Mickan, M. and Sabahi, H.S.R., 2007: Legume seed meals and other plant based fertilisers in organic vegetable production. Zikelki S, Claupbein W, Dabbert S et al (eds). Between Tradition and Globalisation - 9th German Scientific Conference on Organic Agriculture. Berlin:Verlag Dr. Köster.

Oborn, I., Andrist-Rangel, Y., Askekaard, M., Grant, C.A., Watson, C.A. and Edwards, A.C., 2005: Critical aspects of potassium management in agricultural systems. Soil Use and Management 21:102-112.

Oehl, F., Oberson, A., Tagmann, H.U., Besson, J.M., Dubois, D., Mader, P., Roth, H.R., and Frossard, E., 2002: Phosphorus budget and phosphorus availability in soils under organic and conventional farming. Nutrient Cycling in Agroecosystems 62(1):25-35.

Olsson IM, Jonsson S, Oskarsson A, 2001: Cadmium and zinc in kidney, liver, muscle and mammary tissue from dairy cows in conventional and organic farming. Journal of Environmental Monitoring 3(5):531-538.

Paulsen, H.M., 2005: Sulfur in organic farming. Landbauforschung Volkenrode, Special Issue 283:105-110.

Peoples, M.B., Brockwell, J., Herridge, D.F., Rochester, I.J., Alves, B.J.R., Urquiaga, S., Boddey, R.M., Dakora, F.D., Bhattarai, S., Maskey, S.L., Sampet, C., Rerkasem, B., Khan, D.F., Hauggaard-Nielsen, H. and Jensen, E.S., 2009: The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48(1-3):1-17.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D. and Seidel, R., 2005: Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience 55(7):573-582.

Rahmann, G., Oppermann, R., Paulsen, H.M. and Weissmann, F., 2009: Good, but not good enough? Research and development needs in Organic Farming. Landbauforschung Volkenrode 59(1):29-40.

Rusch, H.P., 1964: Bodenfruchtbarkeit. Eine Studie biologischen Denkens. 6. ed, 1991. Heidelberg : Karl F. Haug, pp 1-244.

Ryan, M.H., Derrick J.W. and Dann, P.R., 2004: Grain mineral concentrations and yield of wheat grown under organic and conventional management. Journal of the Science of Food and Agriculture 84(3):207-216.

Schmidt, H. and Haccius, M., 1998: EU Regulation "Organic Farming". A legal and agro-ecological commentary on the EU's Council Regulation (EEC) No. 2091/91. Margraf Verlag, Weikersheim, Germany, pp. 1-415.

Schnug, E., Haneklaus, S., 2006: Aspects of phosphorus fertilization in organic farming. What will organic farming deliver? COR 2006. Aspects of applied biology 79, Warwik, UK:Association of applied biologists: 277.281.

Schnug, E., Haneklaus, S., 2008: Evaluation of the Relative Significance of Sulfur and Other Essential Mineral Elements in Oilseed Rape, Cereals, and Sugar Beet Production. In: Sulfur: A Missing Link Between Soils, Crops, and Nutrition. B. Crops and Sulfur. J Jez (Ed), CSSA-ASA-SSSA: 219-233.

Schnug, E., Rogasik J. and Haneklaus, S., 2003: The utilisation of fertiliser P with special view to organic farming. Landbauforschung Volkenrode 53(1):1-11.

De Kok, L. J. and Schnug, E., 2008: Loads and fate of fertilizer derived uranium. Backhys Acad. Publ. Leiden, The Netherlands.

Scialabba, N., 2007: Organic agriculture and food security. Anon. International Conference on Organic Agriculture and Food Security. pp 1-22. Italy:FAO. 2007.05.03

Scialabba, N. and Hattam, C., 2002: Organic agriculture, environment and food security. In: Anon. (Issue 4) : Food and Agriculture Organization of the United Nations. Sustainable Development Dept, pp 1-252, *Environment and natural resources series*, 9251048193, 9789251048191.

Sir Albert Howard, 1943: An agricultural testament. 1. Oxford and London : Oxford University Press.

Sir Albert Howard and Wad, Y.D., 1941: The waste products of agriculture their utilization as humus. London : Oxford University Press.

Stinner, W., Moller, K. and Leithold, G., 2008: Effects of biogas digestion of clover/grass-leys, cover crops and crop residues on nitrogen cycle and crop yield in organic stockless farming systems. European Journal of Agronomy 29(2-3):125-134.

Sullivan T.W., Douglas JH, Gonzalez N.J., 1994: Levels of Various Elements of Concern in Feed Phosphates of Domestic and Foreign Origin. Poultry Science 73(4):520-528.

Uberschar K.H., 2006: Anorganische Stoffe Kontaminanten - Arsen, Blei, Cadmium und Quecksilber - Vermeidung, Reinigung, Dekontamination, Schlussfolgerungen und Literatur. In: Flachowsky G (ed) Möglichkeiten der Dekontamination von "unerwünschten Stoffen nach Anlage 5 der Futtermittelverordnung (2006)"; (1.2). Braunschweig : pp 31-51, FAL Agricultural Research Special Issue 294.

Van Den Bossche, A., De Neve, S. and Hofman, G., 2005: Soil phosphorus status of organic farming in Flanders: an overview and comparison with the conventional management. Soil Use and Management 21(4):415-421.

Watson, C.A., Bengtsson, H., Ebbesvik, M., Loes, A.K., Myrbeck, A., Salomon, E., Schroder, J. and Stockdale E.A., 2002: A review of farm-scale nutrient budgets for organic farms as a tool for management of soil fertility. Soil Use and Management 18:264-273.

AGRICULTURAL RESEARCH COUNCIL

18TH SYMPOSIUM OF THE INTERNATIONAL SCIENTIFIC CENTRE OF FERTILIZERS

MORE SUSTAINABILITY IN AGRICULTURE: NEW FERTILIZERS AND FERTILIZATION MANAGEMENT

8-12 NOVEMBER 2009
ROME, ITALY

PROCEEDINGS
CIEC 2009

MINISTRY OF AGRICULTURE
FOOD AND FORESTRY POLICIES

18TH SYMPOSIUM OF THE INTERNATIONAL SCIENTIFIC CENTRE OF FERTILIZER

Organized by

1. Agricultural Research Council
    - Research Centre for the Soil-Plant System, Rome
    - Research Unit for Cropping Systems in Dry Environments, Bari
    - Research Unit for the Study of Cropping Systems, Metaponto (Matera)
2. Institute for Environmental Protection and Research (ISPRA), Rome
3. International Scientific Centre of Fertilizers (CIEC)

18TH SYMPOSIUM OF THE INTERNATIONAL SCIENTIFIC CENTRE OF FERTILIZERS

MORE SUSTAINABILITY IN AGRICULTURE: NEW FERTILIZERS AND FERTILIZATION MANAGEMENT

8-12 NOVEMBER 2009 ROME, ITALY

PROCEEDINGS
CIEC 2009

By
P. SEQUI, D. FERRI, E. REA, F. MONTEMURRO,
A.V. VONELLA, F. FORNARO

Web site http://ciec2009.entecra.it

Graphic Project by A.V. Vonella and F. Fornaro (CRA-SCA Bari - ITALY)

Published by CIEC (Italian Scientific Centre of Fertilisers) - FERTILITAS AGRORUM

Printed in Italy
Publishing House "Fertilitas Agrorum" | (http://fertilizzanti.entecra.it/pubblicazioni_fertilitas.html)

ISSN 1971-0755