Development of strategies to improve quality and safety and reduce cost of production in organic and 'low input' crop production systems

L. Tamm[1], U. Köpke[2], Y. Cohen[3] & C. Leifert[4]

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Abstract

The overall aims of organic and low input crop production include the economically viable and environmentally sound production of high quality food and feed. Technological bottlenecks in such systems include insufficient and instable yields and in some instances unsatisfactory processing, sensory and/or nutritional quality of the final product. Recently, concerns have also been raised that the intensive use of manures may lead to increased risk for contamination of food by enteropathogenic micro-organisms. Crop production in low input systems is based on key pillars, i.e. (i) a fertile soil which provides sufficient capacity to allow for plant growth while preventing soil-borne diseases, (ii) high quality, disease-free seeds and plant material, (iii) a crop-specific soil fertility management to provide sufficient nutrients for optimum plant growth, and (iv) adequate crop protection techniques to prevent damage due to noxious organisms. In the QLIF project we develop improved component strategies to overcome technological bottlenecks in annual (wheat, lettuce, tomato) and perennial (apple) crop production systems. In this paper we report the progress achieved so far.

Introduction

One of the principles of organic farming is to attain high quality food production and ecological balance through the design of farming systems, establishment of habitats and maintenance of diversity. Inputs should be reduced in order to maintain and improve environmental quality and conserve resources (Tamm, 2001). However, there are still some 'technological' bottlenecks in organic production systems which potentially affect quality and safety in organic foods, the environment, as well as costs of production. These bottlenecks include insufficient and/or untimely availability of nutrients as well as occurrence of pests and diseases. Similar bottlenecks also need to be addressed in other low input and integrated farming systems. The aim of the QLIF project is therefore to (i) improve the understanding of the functionality of inherent soil fertility as a base of crop productivity and health, (ii) to develop improved agronomic strategies to overcome key technological bottlenecks and (iii) to demonstrate the impact of integration of improved management strategies in annual (tomato, lettuce, wheat) and perennial (apple) pilot production systems. By doing so, we aim to evaluate the overall productivity and quality of the novel systems as well as the economic and ecological impact of the component technologies developed as part

[1] Research Institute of Organic Agriculture (FiBL), Frick, Switzerland, E-Mail: Lucius.tamm@fibl.org

[2] Institut of Organic Agriculture, University of Bonn, Germany, E-mail: ukiol@uni-bonn.de

[3] Faculty of Life Sciences, Bar-Ilan University, Ramat-Gan 52100, ISRAEL, E-mail: ycohen@mail.biu.ac.il

[4] Nafferton Ecological Farming group, Newcastle University, Stocksfield NE43 7XD, UK, E-mail: carlo.leifert@nefg.co.uk

of the project. In this paper we give an overview of the research under way and the progress that has been achieved so far.

Soil fertility and inherent disease suppressiveness

Soil management (e.g. crop rotation, soil tillage, organic amendments) has a significant impact on overall soil fertility as well as specific soil properties such as erosion stability, nutrient availability and water holding capacity (Mäder et al., 2002). Microorganisms play a key role in soil quality and fertility as they are involved in nutrient cycling and transformation processes, as well as soil physical parameters (e.g. soil aggregate stability). Soil microbial communities are affected by short-term as well as by long-term management practices. In general, soil microbial biomass, activity, and diversity tends to be higher in organic than in conventional farming systems (Mäder et al, 2002). Fertility inputs to soils are an important means to improve plant production in agricultural systems. While most conventional or integrated farming systems are based on regular mineral N, P and K fertilizer inputs (that are immediately and easily available to the crop from the liquid phase of the soil solution), fertility inputs used in organic farming systems are based on organic matter inputs (e.g. green and animal manures, composts) only become plant available after unlocking of nutrients from the solid phase by weathering or mineralization processes. Mineralization of these organic matter based fertility inputs by soil microorganisms is crucial for nutrient delivery to the crops in organic agriculture. An active and abundant soil flora and fauna is therefore essential for a rapid mineralisation, and activity of the soil biota is itself affected by soil temperature, moisture and by the chemical composition of the fertility input. Fliessbach et al (2007) evaluated the effects of long-term and short-term effects of organic fertility inputs on soil, physical, chemical and biological properties as part of the long-term DOK trial in Therwil (CH) and from short-term fertility input experiments with lettuce in Bonn (DE) and with onions in Yorkshire (UK). The analyses in the DOK trial confirmed that long-term usage of different soil management strategies lead to different steady state situation with respect to soil properties. The trials at Bonn, Tadcaster and Stocksbridge comprised one single fertilizer application per treatment followed by the growing of an one crop. Among the treatments, fresh bovine manure at Bonn and chicken manure at the two UK sites increased soil biological activity, but it could be excluded that the effects observed reflected temporary peaks (rather than a long-term change), due to the differences in amount and quality of the manures applied.

Soil properties are known to affect the occurrence and severity of soil-borne diseases (Tamm et al, 2006). The extent of disease is the result of the abundance of disease propagules and the competition between crop plant, causal agent and interaction with antagonists in the soil. Crop rotation is widely used in organic and low input farming systems to reduce the survival of pathogenic propagules. Also the presence of specific antagonists or the addition of organic amendments to soil was linked to a suppression of a range of soil-borne diseases including *Rhizoctonia*, *Pythium*, *Fusarium*, *Gaeumannomyces* or *Phytophthora* spp. There is also evidence that soil properties are affecting the occurrence of diseases on foliar parts of the plant. The systematic use of soil fertility management techniques to reduce diseases is an intriguing concept in theory, but it is not yet widely used in practice, partly due to the lack of understanding of the underlying principles. Despite the claims made by some organic farmers, we still find no evidence that reduced foliar disease susceptibility is a typical feature of plants grown in organic farms (Tamm et al., 2005). Within the framework of the QLIF project, the working groups of FiBL, Kassel University and Newcastle

University started a research project in 2004 in order to elucidate the influence of soil properties on soil suppressiveness and to quantify the relative importance of site-specific *vs*. cultivation-mediated soil properties. Preliminary data analysis indicates that differences in suppressiveness may be quantified and related to soil properties and/or organic matter based fertilisation regimes. Furthermore, site-specific factors, which cannot be influenced by agronomic practices, were found to have a greater impact than cultivation-specific effects within the same site. The ongoing research is focussing on verifying hypotheses that aim to identify the underlying correlation between suppressiveness and selected soil properties.

Short-term fertility management and plant nutrition

Nitrogen is a key element in plant nutrition and is in organic production systems often limiting for both, yield and quality. Organic wheat production often suffers from limited nitrogen availability. For example, previous results have revealed that wheat produced in organic and 'low-input' farming systems are characterized by low and irregular grain yield and protein content (David et al. 2007). Typically, it is very difficult to synchronise the nutrient release characteristics from organic matter inputs in soil, with the needs of the crop. The aim of QLIF was therefore to improve the understanding of nutrient release characteristics of the organically managed soils and the nutrient uptake of the crop. The use and adaptation of existing models such as *Azodyn* and *Daisy* (Dux & Fink, 2007) to organic and low-input conditions is the aim of this part of QLIF. The use of models may also allow the quantification of additional limiting factors such as weed competition, drought, soil compaction, or pests and diseases which indirectly affect acquisition and uptake of nutrients.

Soil amendments such as plant-probiotic microorganisms (PPMs) may promote plant growth by biological nitrogen fixation, solubilization of phosphorous, synthesis of siderophores, plant hormones, and plant hormone regulators (Bosco et al, 2007). The indirect promotion of plant growth can occur when soil beneficial microorganisms antagonize the action of phytopathogenic organisms. However, there is still a substantial gap in our knowledge about of the principles and the commercial viability of such amendments. The use of PPM is of particular interest in highly demanding vegetable crops such as tomato. Studies to evaluate novel commercial preparations are currently under way.

Soil management strategies and food safety

Since consumption of uncooked ready-to-eat vegetables becomes increasingly popular, public concern about the microbiological safety of vegetable is also steadily increasing (Trewavas 2001). Recently, concerns have been raised that intensive use of manures might lead to increased risk for contamination of food by entero-pathogenic micro-organisms. Food-borne infection outbreaks have been associated with faecal pathogen contaminations of vegetables (Köpke et al 2007). Such contamination may potentially take place during cultivation and post-harvest handling. Unprocessed bovine manure may be a source of faecal bacteria that might be transmitted to crops that grow nearby the soil surface. However, composting of manures was shown to be an efficient way to reduce pathogen loads. The aim of these studies (Rattler et al, 2005,) was to assess the effect of different fertiliser types on the transfer risk of enteric bacteria in head lettuce. Different treatments of manure application were investigated and the effect of post-harvest handling (e.g. washing) determined. The effect of different fertiliser types (calcium ammonium nitrate, fresh farmyard manure, composted farmyard manure and nettle extract) on the hygienic quality of fresh and washed lettuce was tested in two trials in summer 2004 and 2005. The hygienic quality was assessed by determination of total aerobic bacterial count and level of coliform bacteria, *Escherichia coli*, *Salmonella enteritidis*, Enterobacteriaceae. No *Salmonella enteritidis* was detected in any of the samples. *E. coli* was isolated independent of the fertiliser type in low concentrations. The total aerobic bacterial count, the levels of Enterobacteriaceae and coliform bacteria tended to be lower after application of mineral fertiliser, but were generally at a very low level. The washing process had no significant influence on the hygienic quality of lettuce. No significant differences in enteric bacterial cfu were detected between lettuces grown in soil treated with farmyard manure that was incorporated into soil or left on soil surface. These studies provide no evidence that the use of organic soil fertility inputs poses any additional safety risk, even if worst-case scenarios were studied. Also field experiments with different strategies of physical weed control did not confirm the hypotheses of a substantial pathogen transfer from soil treated with farmyard manure (Fischer-Arndt et al, 2007). Based on these trials, the application of manures in good farming practice could not be linked to any food safety risk.

Pest and disease control

Although a range of diseases are controlled efficiently by agronomic methods (e.g. crop rotation) certain pests and diseases can cause major problems in organic and low input systems. Several EU- and national funded projects aim to develop novel strategies for pest and disease control. In order not to duplicate research efforts, the QLIF consortium therefore focused on gap-filling research in areas which are not covered elsewhere and the integration of novel crop protection techniques developed elsewhere into organic and low input crop production systems (see below).

The prerequisite for successful crop production is the use of disease-free planting material. Seed treatments are one of the options to remove pathogenic bacteria and fungi. In the QLIF consortium, the studies focussed on the development of strategies to obtain disease-free tomato and wheat seeds. Good control of *Didimella lycopersici* was achieved in seed treatments whereas control of *Fusarium* resulted only in slight reductions of damping-off (Kasselakis et al, QLIF annual report 2006). The bacterial disease *Clavibacter* was well controlled not only by acidified nitrite solutions, but also by a wide variety of compost extracts. Another option which is currently evaluated on wheat is to avoid seed contamination by *Fusarium* during seed production. In the present project it was investigated whether spring wheat cultivars differ in sensitivity to seedling blight and this could be linked to differences in early growth rates of cultivars (Timmermanns et al, 2007). Preliminary results confirm that cultivars differ in sensitivity to seedling blight, and that cultivars with higher early growth rates appeared to be less sensitive to seedling blight. If the repetition of this experiment in 2007 confirms the relation between early growth rate and sensitivity to the disease, this knowledge could be used to select cultivars which are more resistant to seedling blight.

Air-borne foliar diseases such as *Bremia lactucae* in lettuce or *Phytophthora infestans* in tomato may cause substantial losses in organic vegetable production systems. Breeding for varietal resistance is very intensive and novel varieties (especially lettuce) are introduced into the market at high rates. However, the varietal resistance is often overcome within a very short period due to the highly adaptive pathogen population. An alternative procedure to protect plants against disease is to activate their own defence mechanisms by specific biotic or abiotic elicitors. In this study

(Cohen, 2007) the efficacy of ß-amino-butyric acid (BABA) in controlling downy mildew in lettuce, especially under field conditions was evaluated. Another objective was to study the mechanism of action of BABA against *Bremia lactucae* in lettuce. A major finding of this study was that BABA was efficient in controlling downy mildew in lettuce under field conditions. Foliar sprays with 201 and 1039 mg/l resulted with 50 and 90% control of the disease, respectively. This result may encourage the introduction of BABA to agriculture as a systemic acquired resistance (SAR) compound against lettuce downy mildew. Due to the fact that BABA occurs naturally in tomato plants (unpublished data) it might also be considered for application in organic farming.

At field level, the need for direct intervention with pesticides can be reduced by promoting build-up of populations of beneficial insects. This approach has been explored in brassica crops in the UK (White et al, QLIF annual report 2006). Preliminary data analysis indicates that companion plants may decrease the number of cabbage root fly eggs and field margin companion plants may lead to increased predator populations not only in mid-European but also in more humid UK climates.

The integration of preventative crop protection strategies

One of the major aims of QLIF-SP3 is to integrate novel preventative crop protection techniques into improved crop production systems. Currently, the production system development is under way in apple, wheat, and tomato. Novel crop component strategies evaluated have been developed in other EU and national funded projects but also within QLIF. In the integration of techniques we focus on studying the effect of novel crop protection concepts and treatments on crop quality and safety, the environment, sustainability and production cost & socio-economic impact.

Tomato production systems: Organic tomato production is limited by soil-borne diseases as well as by air-borne diseases. In order to overcome these bottlenecks, strategies to control (Dafermos et al 2007) soil-borne root and vascular diseases (corky root rot, *Pyrenocheta lycoperici*, and *Verticillium* spp) are developed. The main objectives were to (i) identify alternative strategies for the control of soil borne diseases and (ii) to evaluate the impact of such novel control methods on fruit yield, size and quality parameters. The use of resistant rootstocks was found to an effective method to control soil-borne disease. Grafting onto resistant rootstocks overall increased root fresh weight and mean fruit weight reduced fruit number, but had no significant effect on fruit composition. However, the type of growth substrate used has a significant effect on fruit nutritional composition and taste (sweetness) of tomato. Compared with tomato crops produced in manured soil (the substrate used in organic production) fruit yields, root fresh weights, fruit number and the mean fruit weights from plants produced in perlite (P) fertilized with mineral nutrient solutions and a soil/gravel/perlite mixed substrate were significantly higher. In contrast, antioxidant levels were higher in soil grown plants.

Another serious disease of greenhouse tomato is powdery mildew. In conventional farming systems the disease is mainly controlled by sulphur and other fungicides while under organic farming standards only sulphur products are permitted. However, sulphur can negatively affect the efficacy of insect predators and be phytotoxic in the greenhouse at high temperatures. Previous studies indicated that soil amendment with chitin in combination with the use of resistant hybrids and the foliar spraying with chitosan or plant extracts, may increase the resistance of crops (e.g. cucumber) to foliar diseases. The use of such treatments was also shown to affect the nutritional composition of crops. However, the integrated use of these strategies against powdery mildew and their combined effect on tomato nutritional composition has not yet been studied. Therefore, the objectives of this study were to: (a) assess the efficacy of integrating compost amendment, hybrid selection and application of alternative foliar spray treatments against the powdery mildew of tomato (*Leveillula taurica*) under greenhouse conditions and (b) carry out selected composition analyses to determine the effect of such treatments on the nutritional composition of tomato. Some of the combinations of the above factors were highly effective in decreasing the percentage of disease severity. Specifically the combination of the hybrid of low susceptibility with the addition of chitin in the substrate and the spray treatment Milsana®+chitosan, was equally effective to sulphur. These results indicate that the combination of the above factors could probably be used as an alternative to sulphur controlling *L. taurica* in the greenhouse. Future experiments will further explore the potential of integrated strategies against soil-borne and air-borne diseases and the impact on quality, sustainability and economic viability.

Wheat production systems: Yield and protein content of wheat produced under organic standards was repeatedly shown to be between 20 and 40% lower than levels achieved in conventional farming systems. This is thought to be at least partially due to lower N-supply to the crop later in the growing season and poor adaptation of the currently used wheat cultivars to organic production conditions. Results obtained so far (Wilkinson et al, 2007) indicate that two of the main problems relating to the sustainability of the current organic wheat production methods (lower yields and protein contents) can be addressed by changes in fertility management practices and cultivars choice. Strategies include (i) the promotion of legumes by Rhizobium inoculation of clover seeds prior to the wheat crop, (ii) and the choice of adapted wheat cultivars. Results showed that cultivar choice had the greatest effect on yields, but that fertility management practices also significantly affected wheat yields and protein quality for some of the cultivars. This clearly indicates that yields in organic wheat production can be significantly increased by improved cultivar choice and fertility management regimes.

Apple production systems. Fruit yield, fruit quality and disease occurrence in organic apple production are controlled by a multitude of interacting agronomic factors, the most important being supply of water and nutrients, especially nitrogen input levels and availability pattern during the growing season. The objectives of this research (Lindhard et al, 2007) were to compare single spring application of standard “rapid release“ organic manures (chicken manure pellets) commonly used in organic production systems and traditional ‘organic’ approach based on mineralization driven N-supply from inputs such as compost, which contains very low levels of water-soluble forms of nitrogen, with respect to nutritional status, yields, disease incidence and fruit quality characteristics of apple trees. In this study an optimum compromise between net yield and quality had to be identified. A high production combined with trees less infected with fruit tree cancer and with a satisfactory colouring was produced on trees grown in intensive production system of 5555 trees per ha with no nitrogen supply.

The control of scab caused by *Venturia inaequalis* in organic apple production is still mainly focussed on the use of fungicidal compounds applied in spring and summer. Apple scab control is not addressed in QLIF but in the specialized EU project REPCO (Heiijne et al, 2007). The approach of the EU REPCO project is, to integrate several preventive measurements, such as stimulation of earthworms and micro-organisms to degrade overwintering inoculum, and endophytes to reduce numbers of spores in the orchards. The ongoing research produces novel techniques (preventative and direct control) which will further the development of sustainable apple production systems.

Conclusions

Various approaches to provide optimum plant nutrition and to control key pests and diseases are explored in QLIF. The results obtained so far suggest that substantial progress can be made towards more productive organic and low-input production systems. Several of the novel component strategies do improve not only productivity but can also contribute to a better product quality. The use of manure-based fertility inputs is one of the backbones of sustainable agriculture. Our studies show no indication that such practices may lead to increased risk in food safety even under worst case conditions. The integration of novel component strategies into improved crop production techniques is well under way. In this process, we also integrate novel results from other national and EU funded projects.

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