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Ecological concepts in organic farming and their consequences for an organic crop ideotype

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Abstract

Currently, organic farmers largely depend on varieties supplied by conventional plant breeders and developed for farming systems in which artificial fertilizers and agro-chemicals are widely used. The organic farming system differs fundamentally in soil fertility, weed, pest and disease management, and makes higher demands on product quality and yield stability than conventional farming. Organic farming systems aim at resilience and buffering capacity in the farm-ecosystem by stimulating internal self-regulation through functional agrobiodiversity in and above the soil, instead of external regulation through chemical protectants. For further optimization of organic product quality and yield stability new varieties are required that are adapted to organic farming systems. The desired variety traits include adaptation to organic soil fertility management, implying low(er) and organic inputs, a better root system and ability to interact with beneficial soil micro-organisms, ability to suppress weeds, contributing to soil, crop and seed health, good product quality, high yield level and high yield stability. In the short run, organic crop ideotypes per crop and per market segment can help to select the best varieties available among existing (conventional) ones. However, until now many of the desired traits have not received enough priority in conventional breeding programmes. Traits like adaptation to organic soil fertility management require selection under organic soil conditions for optimal results. The limited area of organic agriculture will be the bottleneck for economic interest in establishing specific breeding programmes for organic farming systems. The proposed organic crop ideotypes may benefit not only organic farming systems, but in the future also conventional systems that move away from high inputs of nutrients and chemical pesticides.

Additional keywords: biodiversity, self-regulation, varietal characteristics

Introduction

Organic agriculture often is described as a natural farming system. It is characterized by refraining from chemical-synthetic inputs, like chemical fertilizers and pesticides. It controls undesirable quantities of crop associates by stimulating the self-regulating capacity of the agro-ecosystem as much as possible, for example by using agrobiodiversity at different levels of management (farm, crop species, variety) within the farming system (Anon., 1991; 2002).

Verhoog *et al.* (2002) concluded that the concept of 'naturalness' as used in the context of organic agriculture not only refers to the avoidance of chemical inputs and the application of agro-ecological principles, but also implies the acknowledgement and appreciation of 'integrity of life'. To be able to further optimize the organic farming system there is a need for varieties that are better adapted to this system and that are in compliance with the concept of naturalness.

Currently, organic farmers largely depend on varieties supplied by conventional plant breeders, who use conventional breeding and seed production techniques and develop varieties for farming systems in which artificial fertilizers and agro-chemicals are widely used. Organic agriculture is not merely a product-oriented farming system and therefore requiring certain variety traits related to productivity, but is also a production-controlled system that takes into account the breeding and propagation techniques and strategies that are partly related to the concept of integrity of life. However, the latter issues are beyond the scope of this paper. They are discussed in Lammerts Van Bueren *et al.* (2002d) and Lammerts Van Bueren & Osman (2002).

This paper describes the kind of variety characteristics required to fit and support a self-regulating, organic farming system from a non-chemical and agro-ecological point of view. First we shall describe in what respect the organic farming system differs from the conventional one to be able to stress the need for different variety traits, analyse the complex and subtle management by the organic farmer using the ecological tools available and describe the role of varieties in this context. Then the characteristics of the organic farming system and its main components will be discussed in more detail, resulting in consequences for the specific varietal characteristics desired. In the light of the perspectives to achieve such traits, ultimately a crop ideotype for organic agriculture will be described.

Materials and methods

Most data for this paper are from research conducted at the Louis Bolk Institute and include variety trials carried out in the period 1993–2002 with several crops under organic farming conditions (Lammerts Van Bueren, 1994; Lammerts Van Bueren *et al.*, 1998; 1999; 2001b; 2002a; Heyden & Lammerts Van Bueren, 2000). Other results are based on information obtained from organic farmers and Dutch seed companies. The information has been completed with literature research.

The self-regulating ability of the organic farm-ecosystem: system stability and yield stability

Although organic agriculture is nowadays known for its avoidance of the use of agro-chemicals and its consequent strive for environmental benefits, organic agriculture is more than merely replacing chemical by natural compounds (Anon., 2002). In organic agriculture one does not want to rely on (phytosanitary) agrochemical intervention because of the application of the concept of integrity of life at the level of the ecosystem (Verhoog *et al.*, 2002). Production, however, remains very important for the organic farmer, but equally or even more important than productivity *per se* is the sustainability of the system. This implies that one appeals more to the ecological, self-regulating and self-supporting ability of the agro-ecosystem (e.g. natural pest control and biotic regulation of soil fertility) through low input, and preventive ecological practices than through high external inputs (Lampkin, 1990).

System stability

The self-regulating ability of organic agro-ecosystems can be defined as the capacity to resist the effects of small and large perturbations or as the presence of enough resilience to counter them without high external inputs (chemical protectants). Such system stability or resilience, which often can be found in multi-species agroecosystems, is important for risk reduction and yield increase (Vandermeer *et al.*, 1998), but also for reducing the population densities of harmful organisms and increasing the densities of beneficial organisms, both in the short and the long run.

Organic agriculture bases its sustainable self-regulating production system on the concept of a farm as an agro-ecosystem. An agro-ecosystem, defined as an ecological system within the agricultural context (i.e. with inputs, withdrawal of products, and interference by the farmer), is shaped by the strong interaction between the (variations in) abiotic and biotic environment, the genetic composition of species involved and the management resources available to the farmer (Swift & Anderson, 1993; Almekinders *et al.*, 1995; Vandermeer, 1995). The biotic diversity includes associated organisms that are harmful to crops, organisms that are beneficial for crop development, and also antagonists or predators of harmful organisms, like predators of harmful insects. All these organisms together contribute to the self-regulating capacity of the agro-ecosystem through balancing or feedback mechanisms (Almekinders & Struik, 2000). The challenge for an organic farmer is to manage and support all these interactions at different levels of the production system in such a way that his farm can utilize ecosystem functions provided by agrobiodiversity, such as biological pest control, nutrient cycling, and water and soil conservation, to increase output, output stability and resource-use efficiency (Southwood & Way, 1970; Altieri & Nicholls, 1999). Organic agriculture regards biodiversity as an irreplaceable production factor or even a driving force at different levels of the farming system, and as an instrument for preventing (too high a pressure of) pests, diseases and weeds (Geier, 2000). Such a self-regulating stabilizing force in agro-ecosystems is not merely provided by a large biodiversity and high numbers of species *per se*, but mostly by a selective number of specific functional species in a proper ratio: functional biodiversity (Southwood & Way, 1970; Altieri, 1999; Tilman, 1999; Finckh *et al.*, 2000). Almekinders *et al.* (1995) stated that as a result of the variation in the factors that determine the agro-ecosystem there is variation in their interaction and in the resulting agrobiodiversity. And because of the hierarchical structure of the agro-ecosystem, variation in management by the farmer is both part of agrodiversity and the factor that manages it. This means that each organic farmer has to find his own way in managing site-specific diversity and identifying the correct assemblages of species (in time and space) that will best realize – through their biological synergism – the self-regulating capacity of his individual farm-ecosystem. Beside the given differences in environmental conditions and the socio-economic context of each farm, differences in cultivation practices, the knowledge, skills and motivation of each farmer result in specific farming styles (Van Der Ploeg, 1990), emphasizing that also the farmer himself is part of the agrobiodiversity-complex. More than his conventional colleague, who has more means to control or overrule diversity, an organic farmer has to translate and apply general ecological knowledge to his specific farm situation (Baars & De Vries, 1999). In the biodynamic part of the organic movement the notion of the above-mentioned unique constellation of every single farm is not only expressed in the basic concept of a farm as an agro-ecosystem, but more specifically in the concept of a farm as a living (developing) organism with its own farm identity or individuality. The specific farm identity can be recognized and characterized, and can then be used by the farmer as a guiding principle to design and fine-tune the appropriate set of measures to enhance the resilience and stability within his farm-ecosystem for optimal farm and product quality (Lammerts Van Bueren *et al.*, 1990; 1992; Klett, 2000).

Yield stability

The reliability of an organic farming system depends not only on (high) yield levels with low inputs but also largely on yield stability. Although organic farmers may gain relatively more system stability after their conversion period and several years of good farming practices, they still have little external inputs to quickly control or correct farm conditions during the growing season against undesired heterogeneous environmental conditions in time (weather, climate) and space (soil, topography). Reduced system stability can result in lower yields and lower yield stability. In humid and temperate climate areas like the Netherlands, yield reductions are mostly due to the infection of crops (varieties) by fungal diseases (Theunissen & Köhl, 1999). In dry years organic farming systems can profit from the higher soil aggregate stability and can in some cases yield higher than the conventional system, where the organic matter content of the soil is often lower due to the use of mineral fertilizers (Raupp, 1996). The fact that yields in organic agriculture fluctuate much more than in conventional systems (see Appendix 1) has become one of the most important factors that limit the growth of the organic market share (Spiertz, 1989; Raupp, 1996; Tamm, 2000; Mäder *et al.*, 2002). This means that more research is needed to further optimize the organic farming system and to understand the different interactions within the system, including research on the role of variety improvement. In our experiences with variety trials carried out with organic farmers, the farmers generally do not so much look for higher yield potential but for 'reliable' varieties that are able to cope with unfavourable weather and soil conditions (Lammerts Van Bueren *et al.*, 2002a). The proper variety can contribute to yield stability because of different specific traits, as will be discussed in this paper, but also because of more general traits such as flexibility, robustness and buffering capacity.

It is in this context of a self-regulating farming system that the organic sector is developing a concept for improved varieties adapted to organic farming systems. In the following sections we will describe the self-regulating organic farming system in more detail by describing soil, weed, pest and disease management, product quality and yield stability, to understand the consequences for the variety characteristics that are required.

Soil management

Soil management in organic farming

In organic agriculture the basis of sound crop production is the care for building-up soil fertility, which is based on three inextricably interrelated components of soil management: the physical (water-holding capacity, structure, etc.), chemical (nutrient dynamics, pH), and biological (soil biota) component (e.g. Vandermeer, 1995). Soil fertility in organic farming means: well managed soil organic matter, good soil structure, diverse soil biota, and a high nutrient and water-holding capacity by using compost and stable manure (Koopmans & Bokhorst, 2000). The idea of an organically well managed soil is that the farmer can build up over time buffering capacity and resistance to an imbalance in growing conditions as part of the strategy to enhance the self-regulating capacity of the farm-ecosystem (e.g. Oades, 1984; Bokhorst, 1989; Jordahl & Karlen, 1993).

The use of organic manure makes the availability of nutrients less controllable, which may result in lower yield stability. On the other hand, in organic systems often a higher soil organic matter content is observed than in conventional systems, which may partly compensate for the yield-limiting effect of the low nutrient availability by an increased water-holding and nutrient retention capacity of soils under organic production. Another matter of attention is that in low(er) input systems, such as organic farming, within-field variation may affect yield stability (Van Noordwijk & Wadman, 1992; Almekinders *et al.*, 1995). Most essential in the use of organic fertilizers is that one needs active soil organisms like earthworms, nematodes, collemboles and mycorrhizae to regulate nutrient cycling processes to make nutrients available to the crops, to maintain soil structure and to suppress pests and diseases (Hendrix *et al.*, 1990). Studies have shown that low(er)input systems harbour diverse soil biota, especially earthworms, more so than the conventional agricultural system (Zwart *et al.*, 1994; Fliessbach & Mäder, 2000). A clear example is provided by a long-term comparison of an organic and a conventional system: the root length colonized by mycorrhizae was 40% larger in the organic than in the conventional system (Mäder *et al.*, 2002). In organic farming systems mycorrhizae are especially important as intermediaries for the uptake of phosphates by the plant. Because of the slow diffusion rate of posphates compared with most other nutrients, their availability to a plant depends much more on the size of the root system, the density of its root hairs and the intensity of its ramifications in the soil (Lampkin, 1990; Ritz & Griffiths, 2001). In conventional farming mycorrhizal associations are generally not considered important because usually large quantities of soluble phosphates are applied.

Beside organic and composted manure also crop rotation and crop residue management are fundamental tools to improve soil fertility. Nutrient catch crops, green manure crops, insect trap crops and crops with a relatively low harvest index, like cereals, contribute to the soil organic matter after harvest (Wijnands & Vereijken, 1992; Struik & Bonciarelli, 1997; Wijnands *et al.*, 2002b) and at the same time may provide other services to improve soil health. Integrating these tools and attuning them to each specific farm, site and soil will be even more important in the future with reduced availability of manure input. This is because in the ongoing development of organic farming the aim is to close nutrient cycles within the organic sector to become independent of stable manure from conventional farming systems (Hendriks & Oomen, 2000; Koopmans & Bokhorst, 2002). With tightly closed nutrient cycles, nitrogen will be less of a problem than for instance potassium and phosphorus, because nitrogen can be supplied by growing legumes that live in symbiosis with nitrogen-fixing organisms, but the losses of potassium and phosphorus will have to be compensated by external inputs.

Consequences of organic soil management for variety requirements

The consequence of the above-described soil fertility management is that in organic farming systems plants have to form and maintain a larger and more active root system for nutrient uptake (i.e. have to be efficient in acquiring nutrients) and will depend more on interaction with beneficial soil micro-organisms that promote nutrient uptake. Therefore organic farmers require varieties that are (1) adapted to such a specific low(er) input soil management and efficient in nutrient and water uptake, (2) have an adequate root system architecture, and (3) can interact with beneficial soil micro-organisms. Moreover, such varieties need to be efficient in the use of nutrients and water, i.e. yield relatively large amounts of desired products per unit nutrient and water taken up by the plant. Such varieties are directly related to higher yield levels, but indirectly – through optimal growing dynamics – also to lower pest, disease and weed population levels (e.g. Van Delden, 2001).

The need for adaptation to low(er) and organic input conditions

To attain yield stability organic farmers require varieties adapted to low(er) and organic input conditions. However, some modern varieties require high nitrogen levels to realize their high-yield potential (Schroën, 1986). Foulkes *et al.* (1998) concluded that the varieties from before and during the 1960s were more nitrogen-efficient than the more recent ones selected under higher nitrogen-levels. But nitrogen-efficient genotypes have also been found among modern wheat varieties in trials under a conventional fertilizer regime (Ortiz-Monasterio *et al.*, 1997; El Bassam, 1998; Le Gouis *et al.*, 2000). Under organic conditions varietal differences in lower-input adaptation have been observed among modern conventionally bred varieties of different crops, including winter wheat (Kunz & Karutz, 1991; Welsh *et al.*, 2001), spring wheat (Lammerts Van Bueren *et al.*, 2001b; Osman & Van Der Brink, 2002) and cabbage (Lammerts Van Bueren *et al.*, 2002a).

Adaptation of varieties to organic inputs also means that the varieties grow at a regular rate, showing that they can cope with less controllable and more fluctuating nitrogen-dynamics without resulting in irregular crop development causing inferior quality due to diseases or disorders. In several carrot variety trials under organic conditions differences in tendency to develop growth cracks were observed (Lammerts Van Bueren *et al.*, 2001b).

Above-mentioned results suggest that improvement of lower-input genotypes can in principle be expected via screening, selection and breeding.

The need for an adequate root system architecture

In organic and lower-input systems, root systems should be able to explore deeper soil layers and be more active than in conventional systems. So organic farmers need varieties with a deep root system that is able to exploit unpredictable and stressful soil environments (water and nutrient availability). There are observations that under poor nitrogen conditions root growth is relatively favoured compared with shoot growth (Brouwer, 1983; Anon., 1985). However, root topology is not only influenced by soil structure and nutrient and water distribution in the soil, but is also genetically controlled (Jenison *et al.*, 1981; Fitter *et al.*, 1991; Fitter & Stickland, 1991), and may be negatively influenced if selection for high yields takes place under high-input conditions with readily soluble nutrients (Siddique *et al.*, 1990). This indicates that selection for adaptation to organic farming systems should preferably be done under organic conditions.

Research is being carried out to find markers linked to genes controlling root architectural traits to be able to incorporate some of the deep-rooting attributes of stress-adapted wild relatives through indirect selection on the marker genotypes (Johnson *et al.*, 2000; Burger & Kik, 2001).

The need to be able to interact with beneficial soil micro-organisms

Because in organic farming systems the input level is lower, a high nutrient uptake efficiency is as much essential as the ability to interact with other soil organisms, such as bacteria and fungi, enhancing plant mineral nutrition (Lee & Pankhurst, 1992; Mäder *et al.*, 2000). Differential interactions between plant genotypes and beneficial micro-organisms have been demonstrated for species of mycorrhizal fungi and plant growth promoting rhizobacteria (Manske, 1990; Smith *et al.*, 1999; Balkema-Boomstra, 2001). Hetrick *et al.* (1993) found that modern wheat varieties are less responsive to mycorrhizal symbiosis, which can be a result of selection under high-input conditions. Although it is known that molecular interactions between micro-organisms and plant roots are genetically determined, no varieties have yet been bred for beneficial interaction with mycorrhizae or other micro-organisms. In the interaction between legumes and rhizobia the presence of nodulating mutants is one of the strongest indications that breeding for more intense interaction with beneficial plant-associated microbes is possible (Jacobsen, 1984). Learning more about the genes involved in these beneficial plant-microbe interactions will yield a more complete picture of plant health and provide new targets for crop improvement (Smith *et al.*, 1999). Since organically managed soils harbour more beneficial micro-organisms than conventionally managed soils, it is obvious that breeding appropriate varieties for such farming systems will require selection under organic soil conditions.

Weed management

Weed management in organic farming

Weeds often are mentioned as the most significant problem in organic farming systems and they are certainly the problem that most concerns farmers who are considering converting their convential farm into an organic one. Because no herbicides are allowed in organic farming systems, the emphasis is on prevention, decision-making (timing) and control technology. The control of yield- and quality-limiting weed populations on organic farms requires strategies that take long-term effects into account. This in turn requires knowledge about the population dynamics of weeds over a rotation, and about the seed setting of weeds (Lampkin, 1990; Kropff *et al.*, 2000). If weeds are not suppressed in time they may become very aggressive (competitive), complete their life cycle and produce a seed bank for the coming years and the subsequent crops in the rotation. The weeds that cause the biggest problems are annual species in the plant row that produce seeds in a short time and throughout the year, such as *Stellaria media* and *Poa annua* (Van Der Weide *et al.*, 2002).

The preventive measures aim at reducing the supply of weed seeds and the multiplication of weed plants, and at destroying weeds before the crop is sown. Measures can be taken at (1) farm level (rotation, intercropping, adjusting row distance – uniform and broad – for adequate mechanical management), (2) crop level (building-up tolerance of a crop by optimizing the growing conditions) and (3) variety level (genetic characteristics for competitiveness through plant architecture, rapid juvenile growth, deep rooting or allelopathic exudates) (Van Der Weide *et al.*, 2002). Not only crops differ in their ability to compete with weeds, but also within crop species varieties have been found differing in competitiveness (Regnier & Ranke, 1990; Lotz *et al.*, 1991; Müller, 1998). Because of the poor competitiveness of winter wheat in an early growth stage, and because of the limited possibilities to mechanically control weeds under the often relatively wet Dutch weather conditions in late autumn, many organic farmers in the Netherlands have switched from winter wheat to spring wheat (Lotz *et al.*, 1990; Lammerts Van Bueren *et al.*, 2001b; Lammerts Van Bueren & Osman, 2002). This example demonstrates the impact that lack of appropriate varieties can have on the organic farming system. It also shows the need for more attention to the characteristic of weed suppressiveness as part of necessary preventive strategies. Apart from practical experiences, in most cases information is lacking on growth characteristics of varieties that contribute to competitiveness, indicating that so far weed competitiveness has received little attention from breeders.

Consequences of organic weed management for variety requirements

The weed suppressive ability of varieties can contribute to the self-regulation principle of the organic farming system especially when under wet weather conditions mechanical weed control cannot be carried out in time or is not effective enough, causing an increase in the labour needed for hand weeding. So organic farmers require varieties that have a rapid juvenile growth and the ability to cover or shade the soil in an early stage of crop development to outcompete weeds for light. This is especially important for crops that grow during winter and early spring when mineralization is low and soils are poorly covered enabling weeds to grow (more) easily, like in the case of winter cereals. In general, a denser crop canopy – as influenced by canopy architecture – improves the crop's ability to compete with weeds. Canopy architecture includes factors such as crop height (cereals), leaf area, leaf angle, leaf stiffness, and leaf shape (Regnier & Ranke, 1990). Most effects of competition for light, water or nutrients can be expected for seed-producing weeds and not for vegetatively propagating weed species. Differences in competitive ability between varieties were shown in several variety trials. The taller varieties of wheat and barley were more competitive, including the ones with either longer or broader leaves, but also those that could establish themselves better in early spring when the mineralization rate is low (Kunz & Karutz, 1991; Eisele & Köpke, 1997; Müller, 1998). Sugar beet and cabbage varieties with more horizontally arranged leaves, and carrot varieties with more and longer leaves were the best in weed suppressiveness because of an earlier closing canopy (Lotz *et al.*, 1991; Lammerts Van Bueren *et al.*, 2001b; Lammerts Van Bueren *et al.*, 2002a). Grevsen (2000) concluded that avoiding semi-leafless varieties or varieties with very small leaves, and using a higher seeding rate could control weeds in organic pea production for the industry. Also in rice systems increased concern about herbicide use induced studies about the competitiveness of rice varieties. Detailed studies on trade-offs between different varietal traits (like competitiveness versus yielding ability or sensitivity to diseases) have to be conducted to make this option feasible (Bastiaans *et al.*, 1997).

Interference of crops with weeds also may involve the production of inhibitory allelopathic substances by the crops' living roots or shoots. Examples are known of genetic differences between crop varieties in growth-restraining effects on specific weed species, but there also are results showing that allelopathic potential may result in reduction of yield or yield quality (Regnier & Ranke, 1990; Balkema-Boomstra, 2002). The latter author concluded that the practical importance of breeding for allelopathic substances might be relatively small and that breeding for more aggressive crops may have more perspectives.

From the above reviewed literature it can be concluded that in principle there are perspectives for more purposeful breeding attention to weed competitiveness among varieties.

Pest and disease management

Plant health; pest and disease management in organic farming

The consequences of losses due to pests and diseases in organic farming systems differ considerably, depending on region, crop, farm structure and market demands. In general, yields in organic agriculture are 20% lower, which is due mainly to a lower nitrogen-input and in some cases to pests and diseases (Tamm, 2000; Mäder *et al.*, 2002). Further growth of the organic sector can be supported if yield stability can be raised by a better control of pests and diseases. Like with weed management, pest and disease management in organic farming systems is interwoven with the total ecological layout of the farming system and with the sophisticated use of agro-ecological knowledge. It aims at increasing the self-regulating capacity and the building-up of a high tolerance to pests and diseases instead of regulation with chemical protectants (Wijnands *et al.*, 2002a). The central concept of plant health in organic farming is: good growing conditions and avoiding stress will enhance the natural tolerance of plants to plant competitors (Bloksma, 1987; Bloksma & Van Damme, 1999). So the occurrence of many plant diseases can be seen not as the cause of inferior growth but as a result of an imbalance between plant and growing conditions, causing an imbalance in metabolism, which attracts insects, fungi and bacteria (Daamen, 1990; Bloksma, 1991; Tamis & Van Den Brink, 1999). Beside the already described soil fertility with good soil structure and water management, diversification strategies like wide crop rotations, mixed- or intercropping, shelter and flowering crops for natural predators, are essential in crop health management strategies at farm level. At crop level, optimization of growing conditions includes avoiding a critical period, broader row and plant distances and optimizing nitrogen supply. The tools a farmer can handle differ in relation to soil-borne, air-borne and seed-borne pests and diseases.

Soil-borne pests and diseases

In organic agriculture most soil-borne pests and diseases can be controlled by stimulating biodiversity in and above the soil, by feeding soil life with organic soil amendments, by good soil management and by choosing site-specific crops in a balanced rotation. Although the power of disease-suppressive ability of (organic) soils and soil life is well known, more research is needed to be able to use soil life as a management tool to increase the power of soil defence in a more controlled way (Hoitink *et al.*, 1997; Van Bruggen & Semenov, 2000).

More research has been carried out on and more experience has been gained with rotations. Although the need for crop rotation is also being recognized in conventional farming, organic farming is simply not possible without adequate crop rotation. Success is intimately related to the choice of the right crops in the right sequence and in the right frequency, suppressing not only populations of soil-borne pests and diseases but also of weeds, and creating a diverse soil life where beneficial organisms flourish too (Francis & Clegg, 1990; Altieri, 1999; Altieri & Nicholls, 1999; Mäder *et al.*, 2002). Most soil-borne immobile pests and diseases, such as cyst nematodes in cereals and *Sclerotium cepivorum* in onion, can be prevented in such organic farming systems, and do not require specific resistance traits in the varieties grown. Only in cases where rotation and soil management do not have the desired effect, like is known during conversion periods and with less or non-specific pests and diseases, resistant varieties can provide an additional alternative. Examples of requirements of organic farmers are sugar beet varieties resistant to cyst nematodes and Fusarium-resistant rootstocks for tomato.

Air-borne pests and diseases

From comparative studies between conventional and organic or reduced-input systems Van Bruggen (1995) concluded that on organic or reduced-input farms root diseases and pests are generally less severe than or just as severe as some specific foliar diseases. Foliar diseases are more difficult to control by biological or cultivation measures than root diseases, because foliar disease development is much more determined by climatic factors than by antagonistic or parasitic interactions on the leaf surface, while the opposite is true for root diseases.

Many foliar pests and diseases are air-borne, so that rotation (diversification in time) plays a limited role, although spatial crop diversification in combination with varietal disease resistance has an effect at a regional level. For most air-borne diseases good crop management will improve the tolerance of a crop. Shortage as well as an overdose of nutrients reduces this tolerance (Tamis & Van Den Brink, 1999). Essential in organic farming systems is building-up and maintaining soil fertility (biotic as well as abiotic components) with – as described before – an active soil life (micro- and macrobiota), good soil structure and crop specific manuring for buffering and resistance to unbalanced plant growth. Another diversification strategy to reduce the spread of pests and air-borne diseases like rusts and powdery mildew in cereals, is through mixed cropping and variety mixtures, creating more within-field genetic variation (e.g. Wolfe, 1985; Finckh & Mundt, 1992; Finckh *et al.*, 2000), and undersowing legumes in non-nitrogen fixing crops (Theunissen, 1997; Altieri & Liebman, 1986). Although such strategies generally have proven to be worthwhile in controlling pests and diseases, more work has to be done to make the gained knowledge more adaptable to specific farm conditions. Other diversification practices to enlarge the self-regulating ability of the farm-ecosystem related to crop health include biological control using natural predators. For that purpose a farmer has to manage an ecological infrastructure (the total of more or less deliberately introduced non-productive elements) on the farm for shelter and food web, like flower rows, ditches, hedges and even certain weeds or herbs (Smeding & Joenje, 1999).

Despite organic management there are still some air-borne diseases that are hard to control, like potato late blight *(Phytophthora infestans)* or apple scab (*Venturia inaequalis*). Such diseases stress the short-term need for non-chemical, natural fungicides or pesticides. The availability of 'natural' sprays on the basis of e.g. *Bacillus thuringiensis*, *Pyrethrum*, and sulfur – which are permitted in the organic sector – is very limited, but such techniques are not the main focus of organic farming systems (Sukkel, 1999). There is much discussion about such sprays, because they have a broad spectrum and beside the target organism also affect beneficial organisms.

Such problems indicate that more tolerant or resistant varieties are urgently needed, thus contributing to adapting the plant to organic farming systems.

Another aspect receiving much attention lately are the mycotoxins produced by *Fusarium* spp. on cereal grain. In a review (Anon., 2000) the Food and Agricultural Organisation concluded that this problem is not larger in organic agriculture than in conventional cereal production. So all research that is focussed on other strategies than chemical protectants to improve the tolerance of cereals against *Fusarium* will also benefit the organic sector (Lammerts Van Bueren & Osman, 2002).

Seed-borne diseases

The EU-regulations on organic farming require the use of organically produced seeds and will no longer allow further derogations for the use of conventionally produced seeds by the end of 2003 (Anon., 1991). This even will encourage the more conventional seed producers to start with seed production under organic conditions and confronts them with the problems of having to control seed-borne diseases without the use of chemical seed and soil treatments. Organic seeds have to fulfil the regular phytosanitary requirements for seeds, so that the production of seeds with or without low levels of seed-borne diseases requires more knowledge and experience than currently available. Although the organic farming system is designed to reduce the disease pressure, an organic farmer expects to start with seeds that are free from harmful diseases, especially when these do not occur on his farm yet, and therefore he makes high demands on seed quality. Especially if growing conditions during germination are not optimal – like in spring – plants can suffer from germination fungi such as *Fusarium* spp. on cereals and grasses (Hulscher & Lammerts Van Bueren, 2001). Other examples of seed-borne diseases that have proven difficult to control in organic crop and seed production are *Alternaria radicini* and *A. dauci* on carrot seeds, *A. brassicicola* on cabbage species, and *Rhizoctonia solani* on seed potato (Lammerts Van Bueren, 1994; Groot, 2002; Lammerts Van Bueren *et al.*, 2002c). With organic seed production more attention is required for the development of varieties that are sufficiently resistant or tolerant not only during ware production but also during seed production.

Consequences of organic pest and disease management for variety requirements

Apart from the question what crop(s) suit(s) best in the given farm context, in what sequence and in what frequency, a farmer uses the possibility to choose among available varieties. The availability of resistant and otherwise organically adapted varieties is an important factor in designing a possible rotation. Because an organic farmer has hardly any curative means, he – in contrast to his conventional colleague – will have to give more priority to varietal resistance, even if this is accompanied by a lower productivity. Because organic farmers very often can keep the disease pressure low using ample rotation and a low nitrogen input, the focus is not merely on absolute resistance; in many cases tolerant or field resistant varieties can be sufficient. The priorities tend in the direction of resistance to air-borne fungal diseases and not soil-borne diseases and pests. Air-borne non crop-specific pests like aphids, and diseases like *Botrytis* require adequate soil and water management. Varietal characteristics can be instrumental for better adaptation to the organic soil and water management attaining a more steady and balanced plant growth and thereby improving the tolerance of the plant for such non-specific pests and diseases. For crop-specific air-borne and seed-borne pests and diseases special cultivation practices in combination with resistant or tolerant varieties are required.

The most important aspect we have learned from variety trials carried out together with organic farmers is that they look for more plant-health-supporting traits in varieties than merely for resistance. For farmers plant architecture is a very important focus when reducing mostly fungal diseases (Lammerts Van Bueren *et al.*, 2001b). For instance, for cereal crops the farmers prefer a longer peduncle and a less compact ear, and for greenhouse tomatoes a less compact growth habit and more horizontally orientated leaves instead of leaves hanging close to the stem. To diversify the breeding strategies for durable resistance Niks & Rubiales (2002) refer to several other, different avoidance and defence mechanisms in plants to be explored. For some crops such a focus is even more important if there is too little knowledge or if there are no adequate tools yet available in organic agriculture to control complex diseases like late blight in potatoes and Alternaria in carrots. The lack of varieties that are fully resistant to these diseases specifically challenges researchers to look for multifactorial solutions, and requires interdisciplinary research including genetic, epidemiological and agronomic strategies (Hospers *et al.*, 2001; Kessel *et al.*, 2002). The strategies in this case focus on crop and farm sanitary measures, different cultivation practices and avoidance strategies with early-bulking varieties, higher disease tolerance, and exploiting differences in resistance components to delay infection and sporulation rate. Due to the problem with *Phytophthora* the assortment of main potato varieties used in Dutch organic agriculture differs totally from the one used in conventional agriculture (own unpublished data, 2001). Such a shift in variety assortment will also take place in the near future for crops where organic propagation is in development and susceptibility for mostly fungal diseases during the seed production phase forces seed companies to carefully select varieties that are suitable to be propagated organically without chemical protection.

Another area on which organic farming will focus more in the future is the suitability of crops and varieties for intercropping, mixed cropping and mixed varieties (Wolfe & Cormack, 2000; Lammerts Van Bueren *et al.*, 2002b). This requires more breeding efforts for an adapted type of plant architecture, for instance to allow an undersown companion crop like clover.

Product quality

Variety characteristics should not only suit and optimize the non-chemical and agro-ecological cultivation practices of organic farming systems and benefit the quality of the environment, but should also lead to optimal product quality for traders, processors and consumers. Part of the (negatively formulated) quality concept is the absence of chemical residues. Organic products are not to be treated with chemical substances, neither before nor after harvest during storage. This is for instance the case with potato and onion where varieties with good long-term storage potential without the use of chemical sprouting inhibitors are much in demand (Lammerts Van Bueren & Van Den Broek, 2002).

Beside the absence of chemical inputs and residues, good product quality also includes positive quality aspects such as taste. Because organic products are not forced into a luxurious growth due to a lower nitrogen-input, they yield on average 20% less, and are expected to taste better (Wende, 1996). The organic sector, in search of improving the quality of taste of organic products like carrots, tomatoes and strawberries, tries to distinguish itself in the market in this aspect. Sensory qualities like taste are not only the result of environmental but also of genetic influences. Simon and co-workers (Simon *et al.*, 1982; Simon, 1993) stated that substantial genetic variation is frequently available for many quality traits in crops like carrot, cucumber, onion and garlic. As breeding programmes until now have paid relatively little attention to these traits and because variation for such traits is available, potential future progress is to be expected (Simon, 1993). Taste is an important criterion in organic carrot variety trials and is included in organic breeding programmes (Bauer, 2000; Hagel *et al.*, 2000; Lammerts Van Bueren *et al.*, 2001b; 2002a).

Another quality aspect that requires attention in the organic sector is improvement of the baking quality of wheat. Because organic bakers are not in favour of using synthetic additives and also prefer home-grown wheat, many variety trials are focussed on varieties with a high bread-making quality and sufficient yield under the low(er) input conditions of organic farming systems (e.g. Welsh *et al.*, 2001; Anon., 2001; Lammerts Van Bueren & Osman, 2002). Several specialized organic wheat breeders already aim at improving the bread-making quality of their varieties (Kunz *et al.*, 1995).

Desired variety characteristics and crop ideotypes for organic farming

Examples for different crops of the variety requirements of organic farmers compared with the chemical solutions in conventional agriculture are given in Table 1. The general variety characteristics as discussed before on the basis of the agro-ecological approach to enhance the self-regulating ability for the main components of organic farming strategies are summarized in Table 2.

The priorities for the above-mentioned, generally required variety traits differ per crop. To obtain varieties adapted to organic farming systems, ideotypes have to be elaborated per crop and per market segment. At the Louis Bolk Institute we worked together with farmers and traders on ideotypes for organic varieties of several crops (Lammerts Van Bueren *et al.*, 2001b). The requirements for carrots differ for different market segments. For organic carrots supermarkets currently demand the same variety performance as for conventional carrots but these are not always the ones best for weed suppressiveness, disease resistance or taste (Lammerts Van Bueren *et al.*, 2001b). For onion the differences lie in the priority for a long storability without having to use chemical sprouting inhibitors during storage. Disease tolerance is re-

Table 1. Examples of variety traits required for organic agriculture from a non-chemical approach, compared with chemical solutions available to conventional farmers.

Crop	Variety traits required for organic agriculture	Chemical solutions available to conventional farmers
Apple, pear	Ability to take up calcium.	$Ca(NO_3)_2$ leaf sprays (apple).
	Little biennial bearing.	Flower-thinning agents.
	Fruit set also under cold weather conditions.	Gibberellic acid to induce parthenocarpy (pear).
	Self-regulating June drop.	Hormones.
Lane trees	Natural tendency to branch.	Branching hormones for roots and stems.
Subtropical fruits	Skin with natural wax layer.	Coating of the skin.
Cereals	Longer peduncle and more open ears against ear diseases.	Fungicides.
Cereals, carrot, cabbage, etc.	Rapid juvenile growth for early soil cover.	Herbicides.
Potato	Hairy and tougher leaves against aphids.	Insecticides.
Potato, onion	Long-term storability without sprouting.	Chemical sprouting-inhibitors.
Onion, cabbage	Leaves with wax layer for tolerance against fungal diseases.	Fungicides.

quired mainly for *Peronospora destructor* and *Botrytis squamosa allii*, whereas *Fusarium oxysporum* and *Botrytis aclada allii* are less of a problem in organic than in conventional agriculture due to the wider rotation and lower nitrogen input. Because of their poor root system onions are susceptible to drought and soil structure problems, which requires varieties with a better root system for efficient water and nutrient uptake (Burger & Kik, 2001). Organic farmers have experienced that leafy onion varieties are more resistant to drought, which is possibly related to a deeper root system. Onion has a poor soil cover throughout the growing season anyway, so that organic farmers prefer varieties with more erect leaves to be able to control weeds mechanically as long as possible without damaging the leaves (Lammerts Van Bueren & Van Den Broek, 2002). The ideotype for organic (spring) wheat shows larger differences (Table 3). Not only disease resistance is important but also a plant architecture that will allow the ears to dry more rapidly following rain or dew by having a longer stem and peduncle, an ear higher above the flag leaf and a less compact ear. Furthermore, a better nitrogen efficiency is required and a leafy crop to cover and shade the soil starting in an early stage (Lammerts Van Bueren *et al.*, 2001b).

Especially the plant architectural aspects come to their minds when farmers with their experience and their farmer's eye are involved in designing crop ideotypes. Such plant architectural aspects are important in organic agriculture in relation to the cultivation practices enhancing the tolerance for various pests, diseases and weeds.

Organic farmers have experienced that there are trade-offs between their varietal requirements. They often have reduced the nitrogen level to half the average in con-

Table 2. General criteria for variety characteristics desired for organic farming systems derived from the agro-ecological approach.

Variety characteristic	Criteria
Adaptation to organic soil fertility management	Adapted to low(er) and organic inputs; able to cope with fluctuating nitrogen dynamics (growth stability); efficient in capturing water and nutrients; deep, extensive root system; able to interact with beneficial soil micro-organisms, like mycorrhizae and atmospheric nitrogen-fixing bacteria; efficient nutrient uptake, high nutrient use efficiency.
Weed suppressiveness	Plant architecture for early soil cover and more light competition; allelochemical ability; allowing and resisting mechanical weed control.
Crop health	Mono- and polyfactorial, durable resistance; field tolerance; plant morphology; combining ability for crop and variety mixtures; capable of interaction with beneficial micro-organisms that enhance plant growth and suppress disease susceptibility.
Seed health	Resistant or tolerant against diseases during seed production, including seed-borne diseases; high germination percentage; high germination rate; high seedling vigour.
Crop quality	Early maturing; high processing (baking) quality; good taste; high storage potential.
Yield and yield stability	Maximum yield level and yield stability under low-input conditions

ventional systems and have accepted a certain reduction in yield (compared with the conventional yield potential) to obtain a more steady growth and tolerance for pests and diseases, and to increase quality traits like taste. New trade-offs may appear when more attention will be paid to the aspects of organic farming systems. Van Delden (2001) pointed out that there could be trade-offs between improved uptake efficiency and weed suppressive ability. Increasing nitrogen uptake by increasing the root:shoot ratio may lead to less weed suppressiveness due to a smaller proportion of biomass in the shoot. Trade-offs require more research and close communication between farmers and plant breeders to discuss the possibilities and limitations of both organic farming systems and breeding.

Discussion and conclusions

That organic farmers use modern varieties does not mean that these are optimal for their farming system. The current modern varieties are adapted to conventional agriculture that has put in a lot of effort to minimize or simply overrule diversity in the cultivation environment, and breeding has mainly been focussed on such relatively standardized farming systems (Jongerden & Ruivenkamp, 1996). In this paper it is explained how organic agriculture substantially differs from conventional agricultural farming systems. Although organic farming systems aim at enhancing the self-

Table 3. The ideotype of a Dutch organic spring wheat variety from a non-chemical and agro-ecological point of view. After Lammerts Van Bueren *et al.* (2001b).

Characteristic	Minimum	Ideal	Priority
Baking quality[1]		Optimal profit.	
Hagberg falling number (s)	260	kg x price for	++
Zeleny value (ml)	35	baking quality	++
Protein content (%)	11.5	as high as	++
Specific weight (kg hl^{-1})	76	possible.	++
Grain yield	ca. 6.5 t ha^{-1} (Lavett)[2]		++
Efficiency of (organic) manure use	n.a.[3]	The desirable profit to be obtained at the lowest manuring level possible.	++
Reduced disease risks			
Stem length	ca. 100 cm (Lavett)	ca. 100 cm (Lavett)	+
Height of ear above flag leaf	ca. 20 cm	n.a.	++
Ear compactness	n.a.	n.a.	+
Stay-green index	n.a.	n.a.	++
Disease resistance[4]			
Yellow rust (*Puccinia striiformis*)	6	8	++
Brown rust (*P. recondita*)	7	8	++
Leaf spot (*Septoria* spp.)	6	8	+
Fusarium spp.	n.a.	n.a.	++
Mildew (*Erysiphe graminis*)	8	8	+
Weed management support			
Recovery from harrowing	n.a.	n.a.	+
Tillering	n.a.	n.a.	++
Days to closed canopy	Like Lavett	Better than Lavett	++
Crop canopy density	Like Lavett	Better than Lavett	++
Risks at harvest			
Straw stiffness	7	8	++
Maturing date	Mid August	1st week of Aug.	++
Seed dormancy	7	7	++

[1] Based on the bonus system used by Agrifirm (trader of about 75% of the Dutch organic wheat production).
[2] Lavett = standard spring wheat variety in Dutch organic agriculture.
[3] n.a. = no quantitative information avalaible.
[4] Based on the values for Lavett (Ebskamp & Bonthuis, 1999).

regulating ability and resilience in the farm-ecosystem, the farmers nevertheless have few possibilities to quickly react and intervene when corrections are needed. This explains why further optimization of the self-regulation principle of organic farming systems requires new varieties with traits that make them flexible and robust with adequate buffering capacity. Organic farmers do not require varieties with a higher yielding capacity in the first place because of risking to lose such profit by (increased) disease susceptibility, but need varieties with a higher yield stability through improved adaptation to organic farming systems and because of that less yield reduction. This paper shows that for organic farmers this implies more than merely a sum of potential resistance traits for pests and diseases. It also requires several additional plant architectural and other growth dynamical aspects of the plant that can contribute to yield stability and reduce the risks of quality and yield loss. So it is very important at this stage of conceptualization of variety requirements and organic breeding programmes that breeders have close contact with organic farmers to better understand the organic farming system with its possibilities and limitations, and to benefit especially from the experiential knowledge of the farmers in their way of notifying important plant characteristics that can contribute to a higher yield stability. Here the farmers' eye can meet and support the breeders' eye in search of the best varieties for organic farming systems.

Referring to the current state of available inputs (practical and scientific knowledge, agronomic tools) our conclusion is that there is a great need and that there are enough arguments and perspectives for improvement and adaptation of varieties to organic farming systems. Such new varieties will outperform the best conventional varieties for organic agriculture.

Until now most of these traits have received little or no attention from conventional breeding and research programmes or do not have the priority they have in organic farming systems. Additional research will be needed to be able to integrate new traits in breeding programmes. Solutions for dilemmas will have to be found in an interdisciplinary and transdisciplinary approach between agronomy, epidemiology and breeding.

Some traits, like adaptation to organic soil fertility management, require selection under organic soil conditions for optimal result (Lammerts Van Bueren *et al.*, 2002b). A bottleneck for the near future, however, will be the limited area of organic agriculture and therefore the limited economic interest of the conventional breeding companies to design specific breeding programmes for 'organic' varieties unless the conventional market can profit from such programmes as well. This will largely depend on societal pressure and governmental policy with regard to the reduction of chemical inputs in agriculture. There are examples that show that as long as chemicals are relatively cheap (conventional) farmers will prefer highly productive varieties to more resistant and sometimes less productive ones (Bonnier & Kramer, 1991; Van Den Berg, 2001). This development prevents in some cases the marketing of resistant varieties for organic agriculture, like is known for spring wheat (Lammerts Van Bueren & Osman, 2002).

In the short run, designing ideotypes with a participatory approach from farmers, breeders and traders can contribute to a more adequate selection of varieties suitable for organic farming systems from among the existing assortment of 'conventional' varieties. For the future our conclusion is that breeding programmes for new 'organic' varieties based on the proposed organic crop ideotype will benefit not only organic farming systems but also conventional systems that move away from high inputs of nutrients and chemical pesticides.

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Appendix

Yield stability of organic farming systems

During the first five years (1980–1984; conversion period) of the Dutch project 'Development of Farming Systems' (DFS) the organic farming system showed lower yields and a higher yield variability than the conventional system (see table below). In the next period of five years (1985–1989) the yields of the organic system remained lower than the yields of the conventional and the integrated (reduced inputs from non-renewable resources) systems due to a lower supply and availability of nutrients, variety choice and a higher incidence of foliar diseases. In both periods the yields of the organic potato crop were highly variable, which was mostly related to the (variable) incidence of *Phytophthora* infection. Although in both periods the yields of winter wheat were lower in the organic than in the conventional system, the variability – expressed by the coefficient of variation – did not differ much from the integrated (in the first period) and from the conventional system (in the second period). The variability of sugar beet in the organic system was comparable with that in the integrated system but in both cases was higher than in the conventional system.

Comparison of average yields, standard deviations and coefficients of variation over two periods of five successive years (1980–1984 and 1985–1989) for ware potato, winter wheat, sugar beet and onion grown in the conventional, integrated and organic farming systems of the Development of Farming Systems project in Nagele, the Netherlands. Data after Spiertz (1989) and unpublished data from Praktijkonderzoek Plant & Omgeving – Akkerbouw, Groene Ruimte en Vollegrondsgroente (PPO-AGV), Lelystad, the Netherlands.

Crop/farming system	Average yield ($t\ ha^{-1}$)		Standard deviation ($t\ ha^{-1}$)		Coefficient of variation (%)	
	'80–'84	'85–'89	'80–'84	'85–'89	'80–'84	'85–'89
Ware potato						
Conventional	49.3	52.4	7.3	2.7	14.7	5.2
Integrated	33.3	52.5	4.7	5.9	14.2	11.3
Organic	27.2	36.2	7.4	11.6	27.2	31.9
Winter wheat						
Conventional	8.0	7.3	0.7	0.8	8.2	11.3
Integrated	7.0	6.8	1.0	0.7	14.7	10.8
Organic	4.4	5.3	0.6	0.7	13.2	12.8
Sugar beet						
Conventional	63.7	–	4.5	–	7.1	–
Integrated	62.3	–	8.7	–	13.9	–
Organic	45.8	–	6.2	–	13.6	–
Onion						
Conventional	–	43.1	–	6.4	–	14.8
Integrated	–	32.4	–	3.8	–	11.8
Organic	–	26.9	–	13.5	–	50.1

The differences in yield stability between the organic and the integrated and conventional systems were highest for the onion crop. Like potato, onion is highly sensitive to weather conditions and to weed and disease pressure: in one of the years the onion yield in the organic system was as high as the yield in the conventional system. Note that after the transition period the yields of ware potato and winter wheat in the organic system considerably increased, whereas the coefficients of variation remained more or less the same.