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Organic Production of Cash Cereals and Pseudocereals

Franc Bavec

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1. Introduction

1.1. Organic production of major cereal crops and maize

1.1.1. General characteristic

Monocotyledonous maize (*Zea mays* L.) and spending winter or spring sown cereals such as common wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), oat (*Avena sativa* L.), and triticale (*xTriticosecale* Wittm. & Camus) provide the main staple foods for the world's human and animal populations. They are conventionally grown on approximately 30 % of the total world arable land, and about 50% of cereals (data from FAO for 2012), provide almost one half of total nutrition energy. Over 500 important industrial products and byproducts may be obtained from maize, and also the similar amount may be obtained from cereals. Their excellent adaptability and wide distribution belongs to the spread family *Poaceae*. For example, wheat is grown from 40° s. l. (Southern latitude) to 60° n. l. (Northern latitude); barley even to 70° n. l. Rye is less sensitive to climate changes than wheat and barley and could be sown at altitudes up to 1200 m under European conditions. Similarly, maize is grown from 53° (optimum 45°) s.l. to 35° n.l., especially wide-spread in areas with a (sub) tropical climate. Especially new crops in the region, like sweet maize in temperate climate needs to be studied carefully [1].

The aim of this chapter was to analyse data mainly from Web Sci and Sci Direct and integrate actual organic cultivation knowledge as a suggestions for further development of maize and cereal production.

The use of organic farming technologies has certain advantages in some situations and for certain crops such as maize [2], but like in case of the yield performances of 24 organic wheat yields were low and variable 3.5 +/- 1.4 t ha^{-1} [3]. The proportion of cereals incl. maize produced organically is relatively high compared to vegetable and fruits (FAO, 2002), due to their less

efficient production and more pretentious marketing. In the USA, 47% of the certified organic area was devoted to field and fodder crops in 2003, compared to 34% to pastures and 8% to fruit and vegetable crops (Economic Research Service, USDA).

In many cases farmers introduce into organic farming the old varieties and land race populations of cereals, because of their better resistance on plant diseases and due to their low fertilizer inputs, but also the yields are lower. Instead of common wheat often grown are spelt, emmer and einkorn in Austria, Switzerland and Slovenia. In spite of high inputs and low resistance on plant diseases, the new (modern) cultivars have changed many of their characteristics (grain size and leaf area have increased almost twenty times, ageing of top leaves has become slower and the period of assimilate accumulation in grains has been extended, better expressed productive tillering by cereals, cereals were bred to produce short-stem varieties to prevent lodging, …).

The competitive strength to weeds is highest for rye, less so for winter barley, oat and triticale, while wheat and summer barley are the least competitive species, due to their height of steams. Monocotyledonous weeds like couch grass (*Elytrigia repens* L.), wild oat (*Avena fatua* L.), hair grass (*Apera spica – venti* L.) and some dicotyledonous weeds like catch weed (*Galium aparine* L.) and perennial weeds like field bind weed (*Convolvulus arvensis* L.), bull thistle (*Cirsium arvense* L.), etc. are associated in cereals. Maize is associated with other group of wide-leaved – to the high temperatures sensitive annual weeds like amaranths (*Amaranthus* sp.), white goose foot (*Cheopodium album* L.), and perennial weeds. Weeds in cereals result in difficult harvesting and cause an intensive spreading of weed seeds and decrease the yield; and additional influence of weeds in maize is suppression of growth in the first leaf stages (Maier code 21-26, [4]).

In organic farming, especially early in the spring at the tillering stage (EC 22-23, see growth stages of cereals described by Zadoks [5] of winter wheat and barley, lack of available nitrogen in the soil is problematic, due to nitrogen leaching and lack of mineralization caused by low temperatures. Rye and oat are less demanding, and thus more suitable for organic production. Also in case of maize the lack of nitrogen in the spring time is a usual problem.

1.1.2. Position in a crop rotation

Success of cereal crop production primarily depends on the choice of the previous crop, especially in less fertile soil. In conventional farming systems, there is a possibility to compensate for a less suitable foregoing crop by using higher rates of fertilizers and pesticides, but in organic farms, residual soil fertility from crop residues primarily determines the potential yield of a cereal crop. Rotation is also essential to prevent the build-up of pests and diseases; in particular foot and root rot diseases.

In mixed farming systems (incl. animal and crop production) where a grass/clover ley is part of the rotation, cereals can be grown after incorporation of the grass/clover mixture or after a more N-demanding intermediate crop grown after grass-clover incorporation, such as potatoes. In stockless farming systems (without livestock), legumes, cereal-legume mixtures, root crops, or oil seed crops are suitable foregoing crops, provided sufficient N is left from the

root- or oil seed crops. In exceptional cases, cereals can be grown for two consecutive years, for example a winter and summer cereal. In that case, it is best to use a less demanding crop (rye or oat in cool climates, maize or millet in warmer climates) as the second crop. Compared to conventional rotations, organic crop rotations generally have a lower proportion of cereals, not exceeding 50%. Above this rate, only crops with low nutrient demands (rye, oat, triticale) can be used. If a legume such as red clover or alfalfa is used as foregoing crop, phytotoxicity od the decomposing residues may be a problem for the germinating seeds of cereal crops [6]. Therefore these foregoing crops should be ploughed under at least three weeks before the cereal is sown.

Because the maize is more demanding for N than temperate cereals, maize is usually grown after a leguminous green manure or fodder crop [7]. Maize is often only rotated with soybeans in conventional production systems, but a corn-soybean rotation does not provide adequate N in an organic system, as most of the N is removed with the soybean. Thus, organic rotations need to include additional leguminous crops besides soybeans or use additional animal manure. A common organic rotation used in the Midwestern USA consists of maize, soybeans, a cereal, legume green manure, and a fifth crop that is varied from year to year [8]. The effects of 2- versus 4-year rotations on corn and soybean yields were studied in organic and conventional systems in Minnesota [9]. Maize in the organic four-year maize-soybean-oat/alfalfa-alfalfa rotation yielded only 7-9% less than in the conventional two-year rotation, and almost twice the yield in the organic 2-year rotation. In another study in Iowa, yields of organic and conventional corn were equivalent in a similar 4-year rotation [10].

Cereal crops also have a useful function for the following crops in an organic rotation, due to their fibrous root systems that may loosen deeper soil layers, depending on the particular crop (Table 1). Moreover, monocotyledonous crops generally are not susceptible to diseases of dicotyledonous crops and, thus, provide a break in the build-up of diseases of dicotyledonous crops.

Crop	Root		Tolerance to yourself	Foregoing crop quality (generally)	Land coverage	Pertinence like cover crop
	Amount	Depth				
Winter wheat	+	++	+	+	+	+++
Spring wheat	+	+	+	-	+	++
Winter rye	++	++	++	++	++	++
Winter barley	+	+	+	+++	+	+++
Spring barley	+	+	++	++	+	++
Oat	++	++	++	-	+	++
Millet	++	+++	+	-	+	++

Explanatory notes: +++ good; ++ proper; + poor; - improper

Table 1. Properties of cereals when used as a foregoing crop (arranged according to Demo, Bielek *et al*. [11].

Crop rotation is also essential for regulation of weeds in cereal crops. Summer cereals should be preferentially grown when winter weeds, such as mouse foxtail (*Alopecurus myosuroides* Huds.), scentless mayweed (*Matricaria maritima* L.), catch weed (*Galium aparine* L.), hair grass (*Apera spica – venti* L.), field poppy (*Papaver rhoeas* L.) are problematic, while winter crops can better be grown when summer weeds (such as wild oats or wild rape seed) occur more frequently. Cereal crops show different competitive strengths against weeds. In general, winter cereals are more competitive than summer cereals, rye more than wheat, and oat more than summer barley. In the low-stem cereals under sown cover crops (from genus *Trifolium*) can be included, because they compete generally well with weeds after harvest and represents the further leguminous in the crop rotation.

Crop rotation also contributes to the regulation of pests and diseases. Black stalk or take-all disease (*Gaeumannomyces graminis)* and eyespot disease (*Pseudocercosporella herpotrichoides*) represent major fungal diseases of cereal crops that are strongly affected by rotation. Take-all is commonly suppressed by antibiotic-producing *Pseudomonas fluorescens* bacteria when wheat is grown without rotation [12], but this is not an option for organic wheat production. In organic farming systems, take-all can be reduced by using soil-improving, non-susceptible annual crops in the rotation, because the pathogens do not persist in soil for a long time period. Suitable *G. graminis*-interrupting crops are maize, oat, potatoes, sugar beet, legumes, rape, or flax. High microbial activity and diversity, promoted by a complex rotation, also contribute to take-all control [12]. Cereal crops need to be interrupted by other crops for at least 2-3 years to limit eyespot occurrence. The most suitable crops for this purpose are clover or alfalfa for 2 - 3 years. Very suitable are sequences of these crops, for example maize - oat, potatoes - oat, potatoes - legumes etc. However, to prevent the build-up of smut diseases, such as *Tilletia controversy* on wheat and *Ustilago maydis* on maize, longer rotations of 6-8 years are required. This is especially true when organically produced seeds are used, as the common seed treatments are not allowed. Too many cereal crops in the rotation may also enhance the risk of foliar diseases such as powdery mildew (*Erysiphe graminis*). Due to low resistance of cereals to the diseases, one of the most effective measures for stable yielding is intercropping of different species of cereals [13] or just different varieties (with the same harvesting time) of one cereal species [14].

The most frequent cereal pests are aphides, damaging the assimilatory organs and spikes. As cereal aphids are quite specific, it is important to rotate with non-cereal crops. In Europe and Western Asia, the corn ground beetle (*Zabrus gibbus*) can be very damaging, especially on wheat [15]. The most damaging pests in maize are corn borer (*Ostrinia nubilalis* L.) and Western corn rootworm (*Diabrotica virgifera* L.), becoming new pests in Eastern Europe. Rotation of cereals with legumes and beet is a sufficient measure against these pests, which' larvae damage green grains and adults feed on crop flowers and grains during milk ripe stages. Wire worms (larvae of the click beetle) can be a major pest in organic crop production, especially after incorporation of large amounts of crop residues, for example perennial fodder crops or a cereal crop with under sown grass-clover. Populations of click beetles are generally reduced by cultivation operations. As root crops and rape seed require multiple cultivation operations, these crops are more suitable for rotation.

1.1.3. Cereal crops management practice

Variety selection

The main criteria for selection of cereal crops and varieties for organic production are: suitability for the certain location, yielding ability, stability and plasticity, large rooting and nutrients uptake ability (especially of nitrogen), resistance to fungal diseases, high competitive ability towards weeds, and stress tolerance (drought, water logging, extreme temperatures). The lower internodes should be relatively short to prevent lodging, but the upper internodes long to support higher ability of assimilation during the period of grain forming, even if the leaves are damaged by fungal diseases. Mid-height and bearded varieties seem to be optimal as these produce good grain yields with fewer productive stalks but with more grains per spike. It is important to select varieties with resistance or tolerance to fungal diseases prevailing at the particular location, as synthetic fungicides are prohibited in organic cereal production, and copper fungicides are generally not used on these crops. In case of maize the special attention must be done to the sowing appropriate FAO groups of hybrids, depending on geographical latitudes (FAO classification valid for Corn Belt in USA, number of growing days for each group growth out of this latitude are longer) and other production demands, and also to the target type of grains (dent, flint, semi dent or flint, pop, sweet) due to it's potential use.

Older varieties of cereals usually have favourable features to low pretentiousness of production inputs, with possible respect to grain quality, but lower productivity. Such varieties can be used for particular contracts with processors, where the price of a specific product balances lower yields.

Preparatory soil cultivation

Soil cultivation is primarily needed for destruction of crop debris and stubble of a previous crop, weed control and mineralization of nutrients, but also to enhance porosity for aeration and water and root penetration. Several cultivation operations can be distinguished, each with their own objectives, for example: ploughing to turn the soil so that crop residues, weed seeds and plant pathogens are buried below the immediate rooting zone, tillage to loosen the soil without turning it, harrowing to prepare a loose seedbed (4-5 cm deep), and hoeing to remove weeds.

The timing of cultivation is extremely important, because the wrong timing can destroy the soil structure, and nullify the benefits of proper organic matter management. This was shown for a biodynamic farm, where soil had been ploughed in a too wet condition, leading to soil compaction. The soil structure was not significantly better than that of a neighbouring conventional farm in comparison to the much better soil structure of permanent grassland. For winter cereals, the soil is obviously prepared for seeding in the fall, but for summer cereals and maize there is a choice of fall or spring soil preparation, depending on the climate. When springs are generally wet, for example in land climates with heavy snow fall, fall ploughing may be the only option, even for spring crops.

The depth of cultivation is another important choice. Common ploughing should not be deeper than usuall, because of live and well structured layer of the soil (suggested 20-25 cm). Even higher ploughing must be step-by step i.e. cm by cm. Recent research has shown that soil organic carbon can be preserved by minimum tillage (shallow tillage, 10-15 cm deep). This also results in minimal disturbance of soil life, particularly fauna and fungi. Many organic farmers opt for shallow tillage, using the so-called eco-plough. After potato for winter cereals or annual cover crops for maize, direct sowing is possible also in organic production. This has resulted in considerable reduction in erosion and nutrient losses, and in improvement of soil structure. However, no-till is hardly an option in organic farming, as herbicides cannot be used, and hand-weeding and mechanical in-row hoeing are not feasible for field crops. Minimum tillage may also result in an increased occurrence of weeds, especially hair grass (*Apera spica – venti* L.), camomile (*Chamomilla*), couch-grass (*Elytrigia repens* L.), creeping thistle (*Cirsium arvense* L.), barnyard grass (*Echinochloa crus – galli* L.), and pig-weed (*Amaranthus* L.), which thrive on compacted soils.

The number of operations and their intervals ultimately determine weed infestation rates. To avoid weed problems in the beginning of crop growth, soils are sometimes harrowed an extra time before final seedbed preparation, so that weeds germinate, start to grow, but are killed by the second harrowing. The first operation is called preparation of a 'false seedbed'. A certain level of weed cover could be tolerated when crops are past their most sensitive stage [16], but noxious weeds should be removed before setting seed. Too frequent tillage operations lead to soil erosion and nutrient and carbon losses, and ultimately to poor soil structure.

Nutrition of cereals and maize

The uptake of nutrients with aboveground maize yields can reach up to 278 kg N ha^{-1}, 46 kg P ha^{-1} and 171 kg K ha^{-1} [17], in cereals approximately up to half of the amount. Target fertilization rate depends on available nutrients in the soil and target yield. Target fertilization rate depends also on climatic conditions, genotype, and production system like plant populations [18, 19]. According to the EU regulations limited input with organic fertilizers is 170 kg N ha^{-1} as an average farm^{-1}. It means that is impossible input the same levels of nutrients in organic production comparing with conventional agriculture. Deria et al. [20] considered that several factors causes grain yield differences (organically grown wheat was: increased at one site by 17%; decreased at three sites by an average of 27%, and not changed at another three sites) between the organic and conventional wheat: like lower nitrogen supply, and lower extractable-P of the organic wheat.

Cereals absorb nutrients mainly from the upper soil layer. Their development depends on available nutrients, especially phosphorus and nitrogen, released from organic fertilizers or crop residues by mineralization.

Nitrogen nutrition is often not limited by the total nitrogen in soil, but by a deficiency in certain growth stages, especially at the tillering stage and generative stages of winter cereals. Release of mineral nitrogen is often maximal in mid summer, often resulting in too high nitrogen levels in brewing barley, but still fairly low nitrogen (and gluten) levels in bread wheat.

Besides crop residues, organic cereal crops may be fertilized with animal manure, especially on poor soils, at rates of 4-10 t ha^{-1} (up to content of 180 kg N ha^{-1} year^{-1}). Also legumes as preceding crops improve nitrogen nutrition on subsequent winter wheat, e. g. the Nitrogen Nutrition Index at flowering (NNIf) = 0.51 +/- 0.12 for a crop rotation with a rate of legumes over 37% vs. 0.41 +/- 0.11 for a crop rotation with a rate of legumes under 25% [3]. In the case of comparing conventional animal production, organic animal production, and organic cereal production residual fertility effects from the preceding crop produced higher yields in organic animal production winter and spring wheat than in conventional. Cultivation of winter wheat in organic animal production was a more efficient use of nitrogen resources than conventional [21]. The findings that microbial properties and N availability with 182-285% increase in potentially mineralizable N, for thus the yields of crops differed under different organic input (regimes cotton gin trash, animal manure and rye/vetch green manure), [22].

Organic fertilizers may also be combined as phosphorus and potassium fertilizers which are allowed (depending on the certification agency).

An additional nutrient dressing can be applied at the generative stages (EC 20–35) by disper‐ sion of dung (5-7 t ha^{-1}) or slurry (20-40 m^3 ha^{-1}). Higher rates of dung or slurry can cause expansion of ruderal weeds (docks, goosefoot, hardship, scentless may-weed, barnyard grass, etc.). Harmonious fertilization maintains the competitive strength of crops, promoting fast foliage growth and better soil coverage.

Additional supply of nitrogen is possible by intercropped legumes. The data showed that nitrogen content of the wheat grain and whole plant biomass significantly increased when the density of beans in the intercrops increased; this was reflected in a significant increase in grain protein at harvest of organically grown wheat [23]. The clear and significant differences in wheat yield and protein content between the organic and conventional systems suggest a limited supply of available N in the organic fertility management system which is also supported by the significant interaction effect of the preceding crop on protein content [24].

Seed selection and sowing

According to EU regulations, if available, certified organically grown seed is required for certified organic crop production (EU Regulation No. 834/2007). As sufficient certified organic seeds of cereal crops and maize are on the market, European organic growers are bound to use these seeds. The situation is different in North America and Canada, where grower-saved seeds are often used, or commercial, conventionally grown seeds without fungicide coating.

The selected sowing rate should ensure an optimum stand density that results in soil shading and weed suppression. Sowing at high density at a narrow row distance is more effective to control weeds in a cereal crop than wide row spacing combined with mechanical weed control. Early sowing is not as effective for weed control as sowing after repeated harrowing (preparing a false seedbed to kill germinated weeds). Finally, the sowing depth is crucial: not too deep to avoid root and foot diseases, and not too shallow to avoid drying of the seed.

Both, cereals and maize can be intercropped by legumes; in the case of maize intercropping with climbing bean is suggested and in case of cereals with pea and beans. Sowing of obove

mentioned intercropped crops is separate, depending on suitable periods for seed emergence and growth.

Weed control

High weed pressure is one of the main problems of organic cereal and maize production. Weed seedbank size was larger under the organic system of maize production than conventional system; and for example differences among maize management systems depends mainly upon weed control efficacy rather than upon tillage effects [25].

The most problematic weed species in cereal production are couch-grass and creeping thistle. Application of herbicides is impossible and thus different ways of weed regulation must be used. The aim of such regulation is not to completely destroy weeds, but to keep their coverage under the damage threshold. The emphasis is put on prevention of introduction and spread of regenerative organs of weeds (seeds, stolons, etc.), and on indirect control like promoting optimal growing conditions for the crops that enhance their competitive strength against weeds. Among the preventive measures belong selection of a location that is suited to a crop's demands, a varied and well-balanced crop rotation including fodder crops, proper soil cultivation, use of barnyard manure, harmonic fertilization, proper choice of species and varieties, proper sowing, prevention of weed introductions, optimum time and way of harvesting as well as post-harvest operations. Finally, care must be taken that noxious weeds don't spread from field margins and surrounding natural vegetation.

If the preventive measures are not effective enough, direct weed control treatments must be applied: mechanical, physical and biological methods. Harrowing using different harrow types (weeders, net harrow, and spike harrow) can be used for deep-rooted crops (maize, sorghum) before the plants sprout but after germination of weeds. A second harrowing can be applied shortly after the stage of 2-3 true leaves (Maier code 21-23). Line weeding (with brush cultivators or deer-tongue cultivators) can be applied in wide-row cereal crops on heavy soils (row spacing over 15 cm) or to combat overgrown weeds when cultivation was delayed, for example due to wet conditions. Thermal weed control (using propane-butane burners) can be used to eliminate all weeds before sprouting of the crop, or to put down dicotyledonous weeds in wide-row crops like maize. Biological weed control by plant pathogens or insect pests is still hardly used in organic agriculture.

Harvesting, post-harvest treatments and storage

Organic grains need to be harvested and stored separately from conventional grains. Perfect threshing and pre-cleaning of the grain is a basic expectation for proper harvesting of cereals. Grain needs to be dried to 13.5 - 14% moisture. Drying of grain is performed gradually, removing only about 2% water at a time if it originally had moisture content over 20%. Organically grown grain should be dried like seed material, preventing too high temperatures, because sprouted grains can be used for human consumption.

Grains of cereals and maize can be infected by fungi that produce mycotoxins (primarily *Fusarium* species), which can seriously affect human and animal health. Therefore mouldy grain should not be used, not even for feeding purposes. To prevent mould infection, grain

temperature, moisture, smell and pest invasion must be monitored, and the storage silos should be aerated. The air temperature should be 5 °C lower than the grain temperature. The optimum temperature for grain storage is 5 – 10 °C, and the temperature should not exceed 20 °C. Storage pests, especially grain weevils (*Sitophilus granarius*), grain moths (*Nemapogon granellus*), and flour mites (*Acari*) can be a serious problem for organic grain, as they can only be controlled within the limits given by regulations. The storage silos need to be cleaned before use. Natural pyrethrums can be used to control invading pests, but these substances have a short-term effect only (5-6 hours), so the application has to be done repeatedly. Natural pyrethrums do not affect warm-blooded animals. If these disinfection procedures are followed, limited occurrence of pests can be expected.

1.1.4. Labour use and economics

Costs and prices

The yields of organic cereals and maize are usually somewhat lower than those achieved under conventional management, mainly due to limited nitrogen availability. However, in a long-term experiment with a five year rotation, yields of organic maize were very similar to those of conventional: 6.4 versus 6.5 tons/ha [26]. In drought years, organic maize yielded even more (28-34%) than conventional maize, thanks to the greater water-holding capacity of the organically managed soil. But in drought conditions in case of organic maize yielded just 38% and 137% relative to conventional were formed [27].

The direct costs for organic grain production are frequently lower than those for conventional production, as there are no expenditures for pesticides, growth regulators (for small grain cereals only) and synthetic fertilizers. These lower costs may sometimes compensate for the lower yields, even at conventional market prices, as observed for maize production in the Corn Belt in the USA [28]. However, for calculation of net income from a crop, opportunity costs need to be included, as less profitable leguminous rotation crops are needed to provide sufficient nitrogen for a corn crop [26, 29]. In addition, more expensive seed, more frequent cultivation and the associated fuel costs, and higher costs for manual labor for preparation of natural fertilizers and weed control detract from the profitability of organic small grain and corn production[26]. Taking the lower yields per ha and all costs per ha into consideration (Fig. 1), the production of cereals and maize would mostly not be economic at conventional prices for the products. Premium prices are essential for a positive balance [26].

Price premiums vary considerably, from 15 to 50% for organic cereals (Sullivan, 2003), and from 20 to 50% for organic corn [29]. Even a premium price of 200% of organic over conventional maize has been reported [30]. The height of the price premium depends, of course, on the kind of cereal, the quality, the extent of processing, the kind of market, and supply versus demand. Especially for maize, specialty crops (sweet maize, pop corn, conserved grains) fetch higher prices than regular feed maize. The premiums will likely remain fairly high as long as the demand for organically grown grains is increasing at the same pace or faster compared to the increase in organic grain production.

However, the economic net return was higher for conventional farming system, but when the economic subsidies from EU were considered, the integrated net return was higher than under organic farming system for wheat and soya [31]. As the demand for organic meat is rising, this should also increase the demand for certified organic feeds, and possibly the premium prices (as long as the number of certified organic grain growers is not expanding as fast or faster). Altogether, it is difficult to predict future organic grain prices [29].

Markets

Depending on the quality of the grain, it can be used as animal feed or for human consumption; grading standards for grains for human consumption are higher than for feed grains [32]. In mixed organic farms, grains are commonly used as livestock feed on the farm itself. Fodder grains can also be sold on the regional, national or international market. However, organic feed grain is generally not transported over great distances. Although it is more difficult to grow organic corn and cereal grains for human consumption due to the higher quality standards, they result in higher net profits than feed grains. Organic cereal grains for human consumption are commonly marketed in different ways than conventional grains, since the buyers are usually smaller-scale than buyers of conventional grain [33]. Organic grain is often produced on a contract, and producers may have more grain than a typical small-scale buyer would need. Thus, organic grain often needs to be stored, and it may be beneficial for an organic grower to have his/her own storage facilities [33]. Some organic farmers process their grain into flour and bread or other cereal products, and sell it directly to consumers at home or at the local market. The greater the share of the production chain is controlled by the farmers themselves, the more profitable the production of cereals will be.
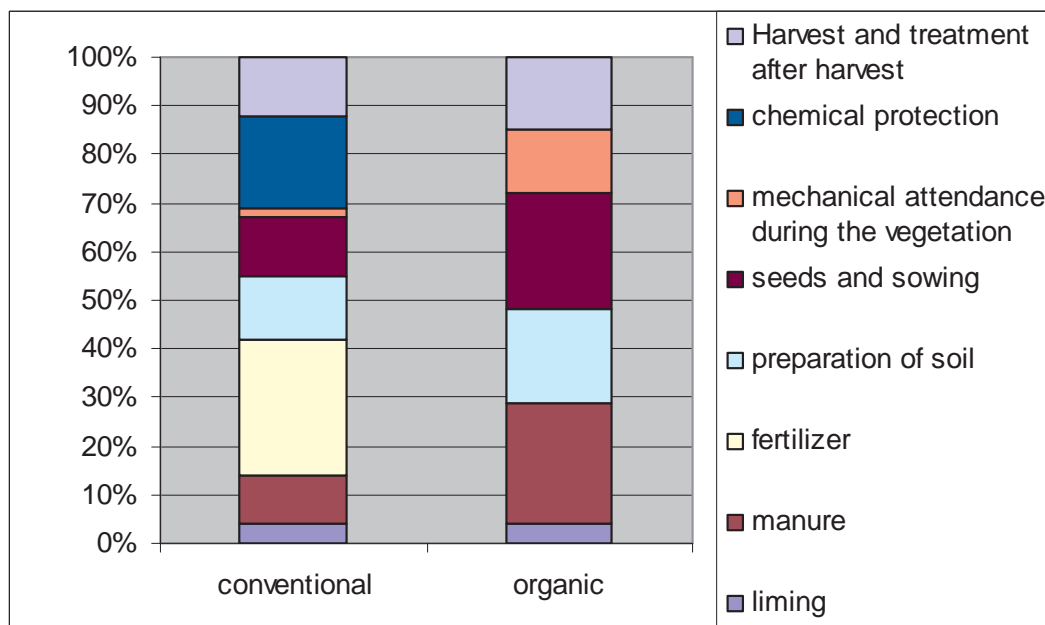

Figure 1. Comparison costs of convencional and organic farming (growing wheat) – variable cost and fixed cost of machines (Moudrý, 2005) – not published data

1.1.5. Ecological impact

The results show a markedly reduced ecological footprint of the organic systems (icluding biodynamic) in production of wheat (*Triticum aestivum* L. 'Antonius') and spelt (*Triticum spelta* L. 'Ebners rotkorn'), mainly due to the absence of external production factors. When yields were also considered, the organic systems again had a reduced overall footprint per product unit and increased ecological efficiency of production. Thus, this farming systems present viable alternatives for reducing the impact of agriculture on environmental degradation and climate change. Nevertheless, room for improvement exists in the area of machinery use in all systems studied and yield improvement in the organic farming system [33].

2. Organic production of pseudocereals

2.1. General characteristics

Pseudocereals described in this book include dicotyledonous field crops of various botanical families i.e. common buckwheat (*Fagopyrum esulentum* Moench) family *Polygonancae*, quinoa (*Chenopodium quinoa* Willd.*)* family *Chenopodiace* and grain amaranths (*Amaranthus caudatus*, *A. cruentus*, *A. hypohondriacus*) family *Amaranthaceae*, which were traditional food in Asia from 10th to11th BC, of Inca's and Aztec civilization, respectively. Their production (Table 2) has become more and more interesting, due to grains nutritional and healthy value, especially if they are gown organically. For those the own experiences at the farm and in research are again evaluated within the scope of new findings cited in research databases.

These crops have an extensive diversification among genotypes, which were utilized and adapted under specific environments; consequently their increasing introductions in the new environments differ in expression of genetic potential of yield and duration of vegetation period to reach full maturity. The main limitations for production under European temperate climate and its above sea altitudes are frost free days during vegetation period and necessary effective temperatures for active photosynthesis (assimilation), except in buckwheat where the temperatures exceeding 24°C cease pollination and stop growth due to short day-length in some genotypes. The main preferences are well adaptation of quinoa and amaranths to dry conditions, soil pH and salinity, and also C_4 pathway in amaranths.

The grains vary in morphological characteristics, shape and weight; for example 1000-g seed weight in buckwheat varies from 18 to 32 (38) g, in quinoa from 2 to 6 g, and in grain amaranths from 0.3 to 1 g. These pseudocereals have a great possibility of niches organic products with high nutritional and healthy value, suitable to diabetics and people with celiac disease, and prohibited milk proteins, etc. In comparison with cereals, grains of these pseudocereals are gluten free food, suitable for people with celiac disease, with higher protein content and their rich amino acid composition, rich in fibers, polisaturated (gamma) fatty acids incl. squalene in amaranths and minerals, etc. (Table 3), however composition depends also on milling fractions and food processing. All three pseudocereals are rich in lysine (the first limiting essential amino acid in cereals); quinoa also in histidine, isoleucine and metionine + cystine, its' consumption

	Buckwheat	Quinoa	Amaranths
Production			
Origin of utilization[a]	Asia, highlands	Andes mountains	South America
Main producers	Russia, China, USA, Japan, EU[b]	Peru, Bolivia, Argentina[c]	USA, Peru, Bolivia[b]
Yield (kg grain ha^{-1}) - approximate	800-1000[b]	400-1200[b], 640-920[c]	400[b]-1500[a]
minimum, maximum	500-2200[b]	435-6591[b]	10[d]-4000, 5000[b]
Requirements			
Growing season (days)	100	120-240[e], 140[f]	105-160[b], 150[f] 90[g,h]-100[h]
Min. germination temperature (°C)	7[f]	5[f]-7[b]	12, 15[i]
Frost resistance to (°C)	-1[f], (-1.3 to -2.9)[j]	-3 do -15[k]	0
Temperature stop assimilation (°C)	10	8	15
Transpiration coefficient (kg water kg^{-1} of dry plant matter)	500-600[b]	400	200-333[k]

Sources: [a] [35], [b] [36], [c][37], [d] [38], [f] [39], [g] [40], [h] [41], [i][42], [k][43], [j][44], [k][45]

Table 2. Pseudocereals production characteristics and environmental requirements

less than 50 g of grain per adults' daily need, it is also ideal reference of essential amino acid pattern for children according to FAO/WHO/UNO standards (except for valine); amaranths are a substitute for meat meals, especially due to rich content of methionine, cisteine and arginine [45, 36]. For those mixtures with cereals supports balanced meals in amino acid composition, especially for vegetarians.

	Buckwheat				Amaranth	Quinoa
	Seed	Groat[b]	Dark flour[a]	White flour[a]	Variation	Average[f] (variation)
Protein	11-15,12.3[a]	16.8	14.1	6.4	13.3[c]-17.9[d]	14.7 (9.6-22.1)
Starch	73.3[a]	67.8	68.6	79.5	62[g]	58.2 (46.9-77.4)
Fat	2.3[a]	11	3.5	1.2	5.1-7.7	7.2 (1.8-8.2)
Fibre	10.9[a]	0.6	8.3	0.5	8 [g]	6.4 (1.1-13.4)
Ash	2.1[a]	2.2	1.8	0.9	3 [g]	3.4 (2.4-9.7)

Sources: [a] [47], [b] [48], [c] [46], [d][49], [f] average data from Fleming and Galwey [50], [g][39].

Table 3. Nutritional composition of pseudocereals (% of dry matter)

In addition pseudocereals are characterized by many health-important substances like antioxidants – flavonoids: rutin, isovitexin, etc., flavones, phytosterols, fagopyrins and thiamine binding proteins and prebiotic activity in buckwheat. Consumption of buckwheat can improve diabetes, obesity, hypercholesterolemia, constipation as well as reduce blood pressure and cellular proliferation. The most important component in amaranths is squalene, which affected synthesis of cholesterol, possesses antisclerotic properties and may be used in the prophylaxis against cancer (see references in Bavec and Bavec[36]. From quinoa grains leached bitter saponins represent natural substances used in organic detergents, soaps, shampoos, cosmetics, etc.; the high-growth cultivars of amaranth are suitable for energetic purposes.

Among pseudocereals buckwheat is the most weed resistant crop which results from its fast development in early growth stages and might due to allelopathy [51].

In buckwheat do not exist disease and pest infestation, which might cause economically important damages, except emerging plants by nematodes. Also quinoa and amaranths should not require special pest and disease control. But several species of cosmopolitan polyphagos pests (e.g., *Agrotis ipsilon* Hufnagel, Lepidoptera: nuctuidae) may cause economic losses. Some of widespread pests endemic to the Andean region may cause up to 50% loss of yield in quinoa, especially two species of moths (*Eursacca quinoae* Povolyny, *E. melanocampta* Meyrick) [52]. Emerging plants may also be damaged by flea beatles and caterpillars. Diseases caused by *Peronospora* sp., *Sclerotinium* sp., *Phoma* sp., *Botrytis* sp, and *Pseudomonas* sp. may have an influence on yielding of quinoa. However, viruses found on spinach or beets have been observed also in quinoa fields.

2.2. Position in rotation

Because of previously mentioned plant diseases and possible polyphagous pests which could appear, and increase of weeds, each pseudocereal may not be planted again on the same field for at least 3 years; 5-6 years is suggested in organic farming. A negative consequence of incorrect buckwheat crop rotation is also increased occurrence of necrosis and the appearance of some disease signs, especially root diseases caused by *Gaeumannomyces* sp. In spite of amaranths, quinoa seeds also do not exhibit dormancy and they germinate when conditions are suitable; the plant itself though, in wild form, may remain in soil for 2 to 3 years without germinating.

According to different requirements about nitrogen needs in amaranths (high nitrogen accumulative C_4 plant), recommended rest of available nitrogen (after precrop and/or additional fertilization with organic manure) is high in comparison with buckwheat, due to lodging in the case of high value of available nitrogen in the soil [36]. However, suitable precrops crops are cereals, grain legumes and perennial legumes. Buckwheat appears as a very suitable precrop for fiber flax due to its strong competitive strength against cough-grass and dicotyledonous weeds. Considering its shorter growth season can be used as stubble crop after early harvested previous crops (early potatoes, barley, crop-legumes mixtures for green feeding). Because amaranths and quinoa growth slowly than buckwheat during early growth stages, the field in quinoa, and especially in amaranths, must be free of weed competition, for those

precrop must suppressed the weeds. Buckwheat, sown as crop, cover crops or for green manure, may produce allelophatic substances that could inhibit weeds [51] and also follows crop in rotation.

2.3. Crop management

Species and varieties selection

In common buckwheat exist more than 4500 different varieties and land race populations, but in every climate special attention should be given to choosing appropriate cultivars, because of different photoperiodical reactions.

From more than 60 wild species of genus *Amaranthus*, four of them were selected like grain amaranths. They are different among each others in germination [42], growth, habitus, inflorescence, ripening and seed colour [53].

The genus *Chenopodium* consists of 150 species, classified into 16 sections. Few plants from section *Chenopodium* are used for human consumption. Quinoa is the most important species from genus *Chenopodium*. In the first stage, cultivated genotypes originated from 6 ecotypes and 4 plant populations from different regions [36]. Also in amaranths and quinoa introduction of new cultivars must based on previous analyses of trials results in every new climate.

Fertilization

Pseudocereals requirements for nutrients need vary from low to very high. Organic fertilizers that are left over from the preceding crop or given stable manure in autumn provide adequate yielding in the organic production system. Modest available level of nutrients results in low yields, except in case of some heavy metals in amaranths (important remediate plant), and Ca-bound phosphorus in buckwheat, which efficiency might be influenced by acidify of the rhizosphere [54] compared to spring wheat. In buckwheat in case of more than 20 g NO_3-N kg^{-1}dry soil to the depth of 0.3 m fertilization with nitrogen manure is not allowed, due to possible lodging problems; it should instead be used for the previous crop in the crop rotation [36]. Although amaranth yield is responsive to available nitrogen in the soil like maize, but a high level of available nitrogen can negatively affect grain harvest in terms of increased lodging, and delayed crop maturity [55]. Nitrogen application up to an Nmin target value of 140kg N ha^{-1} raised protein concentration in grain of amaranths, and maintained the content of essential amino acids in protein. Essential amino acids in grain fertilized to the target value 140 kg N ha^{-1} was higher (397 g kg^{-1}) than the standard requirement for preschool children (339 g kg^{-1}). Among essential amino acids, only valine concentration responded to nitrogen supply. Leucine was the limiting amino acid in grain protein [56, 57]. In quinoa, compensation is suggested by organic fertilizers at an application rate of about 120 kg of N ha^{-1} [58] for the expected enhancement of grain yield.

Sowing

Buckwheat is often sown as stubble crop, amaranths and quinoa are main crops. Different sowing methods, including sowing rates variy among buckwheat (mainly suggested 200 – 300; row spacing is from 12.5 to 25 cm, sowing depth is about 2-3 cm, sowing rate is 1,0 1,5 mil.

seeds, i.e. 40-60 kg per ha. Late sowing, for example on weedy fields, is recommended to be done using closer row spacing and higher sowing rates. Greenhouse experimental data in quinoa showed that optimal plant populations varies from 30 plants m^{-2} [58] to an optimal plant population of 140 plants m^{-2} [59], to 200 plants m^{-2} in the 2.3 field trials (Jacobsen et al., 2005) with interrow spacing 0.4 to 0.8 m. In amaranths 0.12 to 08 m interrow spacing, 150 to 200 seeds m^{-2} and final plant population about 40 plants m^{-2}. From variable data we can stress that in *A. cruentus* cultivars would be recommended above 30-cm row spacing and populations of 74000 and 272000 plants ha^{-1} [40].

Yields of *A. cruentus* cv. 'G6' were affected by growing season and date of sowing. There was a higher protein content (165 g kg^{-1}) and lower (39.3 g kg^{-1}) in grain of plants sown in May and June, respectively [57].

Harvesting, post-harvest treatments and stocking

According to botanical distinction harvesting, postharvest techology and food processing [60] vary in comparison with cereals, except seeding machines, harvesters and mills in buckwheat. Buckwheat is harvested when about 75% of the seeds have reached ripeness, in quinoa when at the maturity stage, plants become lighter and more yellow, and the leaves fall off and in amaranths the appropriate harvesting period is indicated by the yellowing of bottom leaves and dry seed [36]. After harvesting, which can be done with special adaptation of cereals or clover threshers, must follow immediate winnowing, after-drying to 10-12% water content and placing in a slot-floor storages equipped with an air ventilation system. Storage facilities must be dry and airy.

2.4. Labour use and economics

Pseudocereals as low input crops (labor, fertilizers) have a petty differences between yield in conventional and organic farming system, where production should be more profitable according to higher prices of organic products.

3. Conclusions

Cereals and maize are the most important food and fodder crops also in organic farming, they are essential rotation crops, as long as they are not taking up more than 50% of the crops in the rotation. Cereals are more suitable for cool and humid climates than maize, due to the slow initial growth caused by low temperatures and less expressed weed competition. Well structured soils and enough available nutrients in the soil based on crop rotation and inputs of organic manures, and systematic use of other preventive and corrective measures for pest, disease, and weed control will contribute to stabilization of yield at about 80-90% in comparison with conventional crops, depending on climate and soil type. Using organic price premiums for organic crops, net incomes from organic cereals and maize are higher than those of their conventional counterparts.

Buckwheat, grain amaranths and quinoa are very suitable crops for organic farming, especially for small scale farms. They extend agro-biodiversity and range of niches organic products, also for special uses. For an effective production selection of varieties and appropriate growing conditions should be studied and knowledge of post harvest technology and food processing must be detailed and up to dated.

Author details

Franc Bavec[*]

Address all correspondence to: franci.bavec@um.si

University of Maribor, Faculty of Agriculture and Life Sciences, Hoce, Maribor, Slovenia

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