Organic Plant Breeding: Achievements, Opportunities, and Challenges

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During the development of the organic agriculture movement it became obvious that crop plant varieties released from conventional breeding programs do not cover all requirements and demands of organic systems. A number of organizations were founded around 1980 to 1990 to i) safeguard genetic resources on farm and in garden, ii) produce and distribute organic seed, and iii) start organic breeding programs. Organizations include e. g. MASIPAG / Philippines, Seeds of Change / USA, De Bolster / Netherlands, Arche Noah / Austria, Pro Specie Rara / Switzerland, Kultursaat and Dreschflegel / Germany, and Garden Organic`s Heritage Seed Library / England. Prior to this time little organic seed was available exclusively from a few pioneers.

Aims that many of us agreed upon were

- the adaptation of varieties to organic growing conditions,
- to (re-)establish farmers and gardeners as breeders,
- reduce external input (seed) into the farm organism,
- appreciate the holistic nature of the plant and its integrity,
- use the potential of open pollinated varieties,
- create a cooperation between breeders, growers, and consumers,
- increased varietal diversity, and
- high food quality.

In the meantime some organic breeding projects have yielded encouraging results and some academic working groups have investigated and improved organic breeding methods. The first academic textbook “Organic Plant Breeding” (Lammerts van Bueren and Myers) is to be published in 2012. The objective of this article is to highlight some successful approaches to organic plant breeding and to encourage the organic movement to engage in an increasing number of organic breeding and organic breeding research projects.

The need for organic breeding programs

In paired organic / conventional selection experiments with wheat (Murphy et al. 2007, Reid et al. 2011) and maize (Burger et al. 2008) it has been demonstrated that the best genotypes for organic cropping are **selected within the organic system**. Murphy et al. (2007) have demonstrated that the top yielding soft white winter wheat breeding lines in organic management did not correlate to the top yielding ones in conventional management in four out of five paired trials (Fig. 1). Spearman’s rank correlation coefficient revealed no positive genotypic rank correlations among systems in locations 1-4. Direct selection in organic systems produced yields 15%, 7%, 31% and 5% higher than the yields resulting from indirect selection for locations 1–4, respectively. Differences observed at location 5 were not significant.

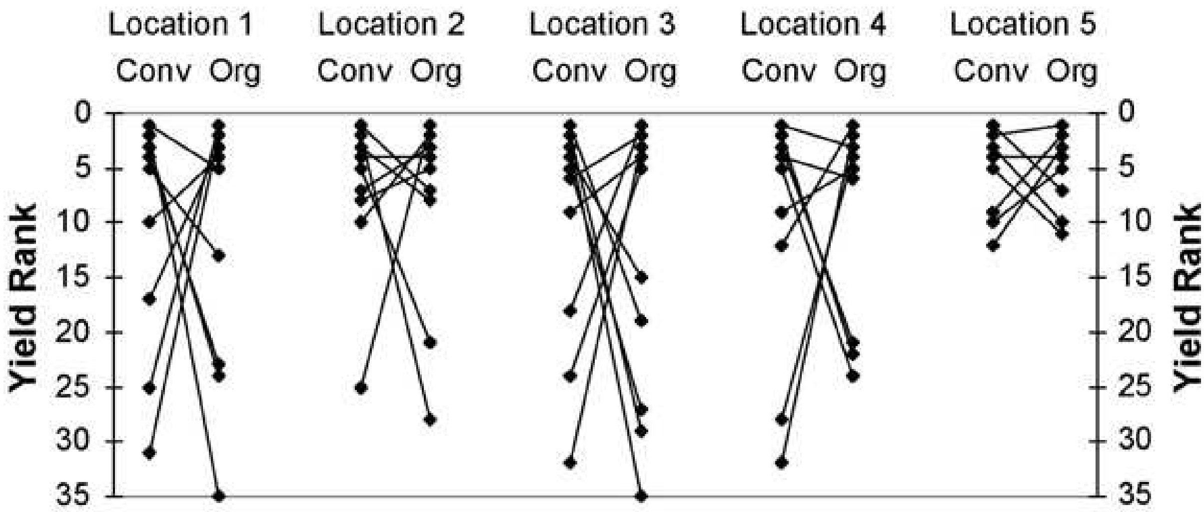


Fig. 1. Genotypes' change in rank between organic and conventional wheat nurseries. The top five ranking genotypes for yield in both organic and conventional systems were compared at each location. Genotypes are ranked from 1 = highest yield to 35 = lowest yield (Murphy et al. 2007).

Burger et al. (2008) tested experimental single-cross maize hybrids in two paired conventional and organic trials. The results shown in Fig. 2 clearly indicate that the top ranking hybrid varieties in organic management do coincide with those adapted to conventional management only to a very limited extent.

In the words of Murphy et al. (2007) "With crop cultivars bred in and adapted to the unique conditions inherent in organic systems, organic agriculture will be better able to realize its full potential as a high-yielding alternative to conventional agriculture."

The superior performance of breeding lines selected within organic system is the result of a number of important traits some of which will be dealt with in the next sub-chapters. It is an advantage of breeding within organic systems to be able to select for individual traits like weed tolerance, nutrient use efficiency, and field resistance against pests and diseases as well as the interactions among these traits.

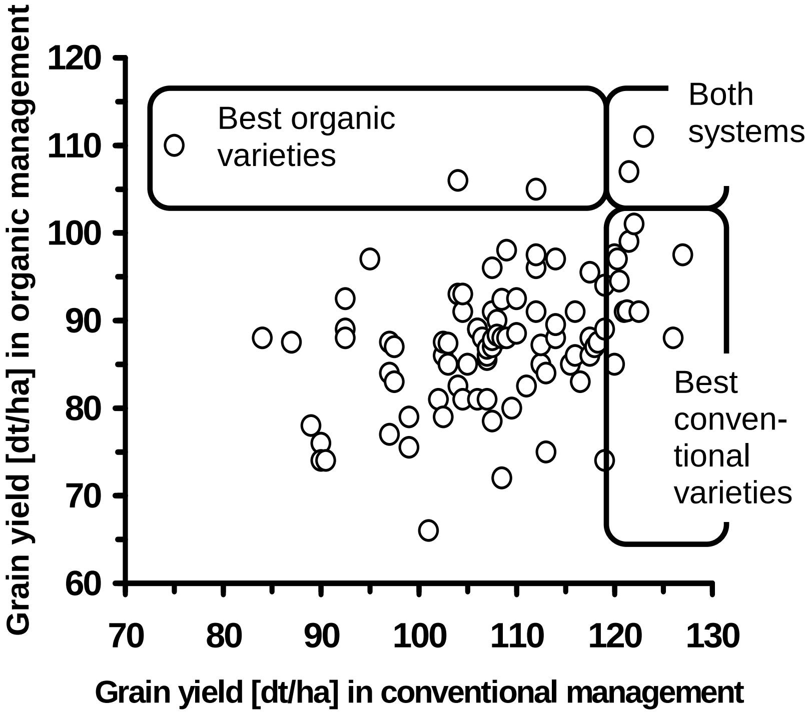


Fig. 2. Performance of maize hybrids in conventional and organic management (Burger et al. 2008, modified).

Crucial traits

for many crops in organic systems are **weed tolerance**, **field resistance against pests and diseases, nutrient use efficiency,** and **adaptation to nutrient dynamics**. These traits are of varying importance in conventional system depending on the input level of herbicides, fungicides, pesticides, and mineral fertilizer.They may be beneficial to reduce input and solve particular problems. Organic breeding has the potential to improve conventional agriculture, too.

Weed tolerance

is a very complex trait. Few experiments have investigated varietal differences. No results from breeding programs for weed tolerance were available for this article. The most important aspect is the morphological weed suppression ability that for instance in cereal grains includes height, early season growth, tillering capacity, and leaf area index (Mason and Spaner 2006). The identification of competitive crop idiotypes may assist organic breeders in the development of competitive varieties. The tolerance to mechanical weed control is important in many organic systems. It may be related to the strength of the roots, root distribution, and leaf-arrangement. Generally competition in the root sphere is little investigated.
In breeding projects intercropping with suitable cultivated plants of selected species can be used to simulate weed competition, because natural weed pressure frequently is not evenly spread throughout the test plots. This approach, however, has a little drawback: it fails to investigate allelopathic effects between weeds and crop plants that may either be positive or negative for crop development. Wolfe et al. (2008) stated that little is known about allelopathic effects under field conditions.

Breeding for **field resistance against diseases** has been successful for e.g. barley and tomato.

An example for fungal pathogens restricted to organic agriculture are the smut fungi of cereals, e.g. loose smut (*Ustilago nuda*) and covered smut (*Ustilago hordei*) in barley. In conventional agriculture smuts can be controlled completely by seed treatment with fungicides. In organic management seed borne spores can be controlled e. g. by hot water treatment. This method, however, is not efficient enough to meet the threshold given by the authorities for the production of certified seed. Screening for resistance within organic systems was successfully carried out by Lorenz et al. (2006).

The host – pathogen system Tomato – late blight (*Phytophthora infestans*) is rapidly evolving on the global scale favouring more aggressive *Phytophthora* strains (Foolad et al. 2008, Deahl et al. 2008). As a consequence the cheap and resource-efficient outdoor tomato production has almost ceased to exist in those regions of Europe with humid climate. Horneburg and Becker (2011) have developed successful selection methods for improved field resistance in organic management. Screening and breeding in organic management was carried out with participation of market and amateur gardeners, seed savers, advisors, seed traders, and scientists and led to the registration of new improved varieties for low input organic outdoor production (Horneburg 2010). Colleagues in conventional agriculture can profit from our work because the waiting time after a fungicide treatment in some cases does interfere with the tomato harvest.

Nutrient use efficiency and **adaptation to nutrient dynamics** and **abiotic stress** have only been investigated to a limited extend in organic agriculture and research results are barely used in breeding. Presterl et al. (2002) have shown in conventional studies with varying nitrogen (N) supply that the potential for selection is high in maize. Experimental hybrids of European elite breeding lines selected at low N (L) out yielded those selected at high N level (H), when tested in low N field trials (Fig. 3).

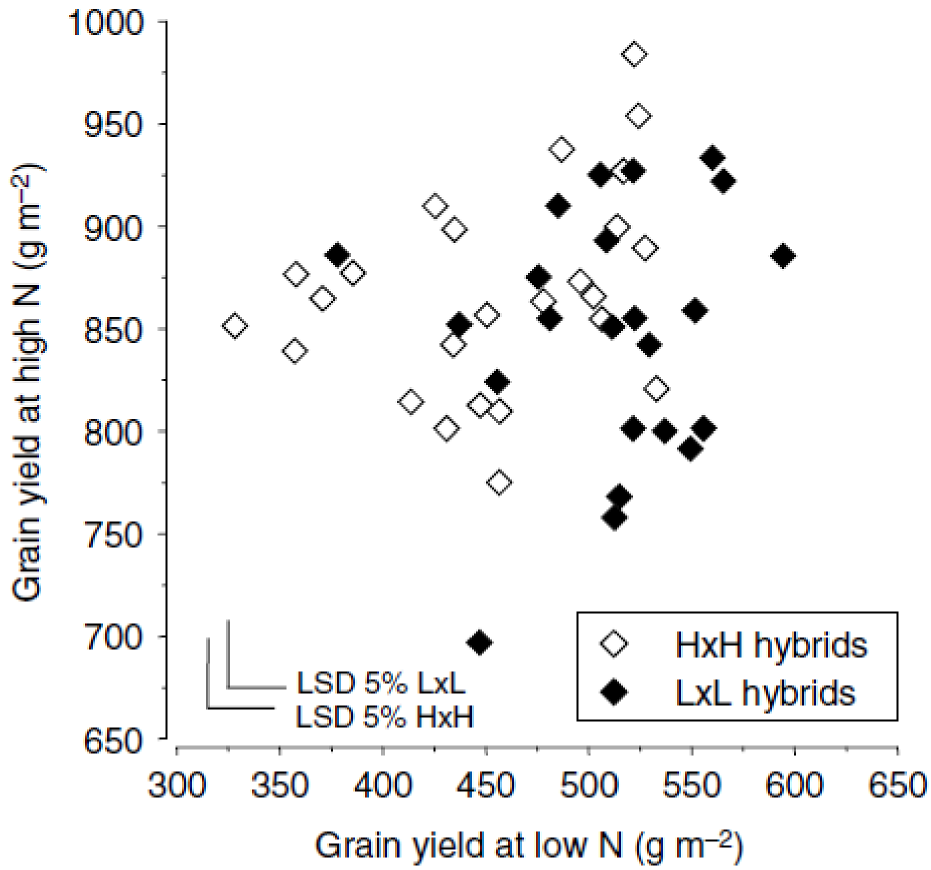


Fig. 3. Relationship between grain yields at low and high soil nitrogen levels of 25 H x H and 24 L x L maize hybrids, respectively (Presterl et al. 2002).

Ceccarelli (1996) evaluated extensive trials with barley in **low input** semi arid environments. The predominant **abiotic stress** factor was water deficit. Breeding lines selected in low and high yielding environments, respectively, were compared in trials covering a wide range of yield level (Fig. 4). Lines selected in low yielding environments performed better at a low yield level while they were out yielded by lines selected in high yielding environments at high yielding environments. Farmers' fields corresponded to low yielding environments; breeding stations were managed at a high yield level. This study did not investigate a single nutrient in a factorial design, but the general nutrient level and the interactions with water supply and cultivation techniques. Organic agriculture needs varieties that perform well with a limited nutrient level and that are adapted to the nutrient dynamics that occur in times with little mineralization.

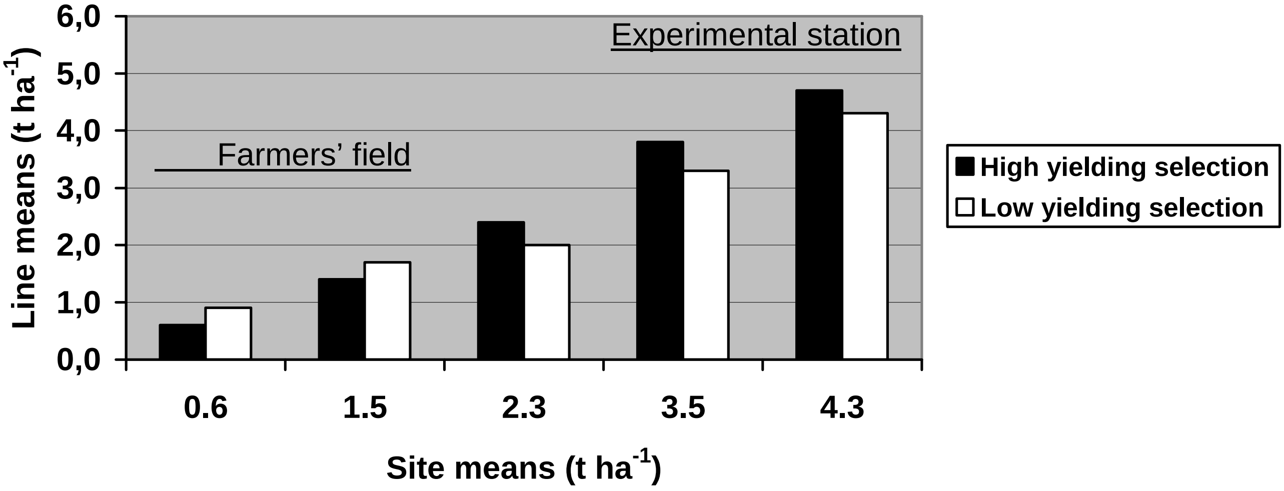


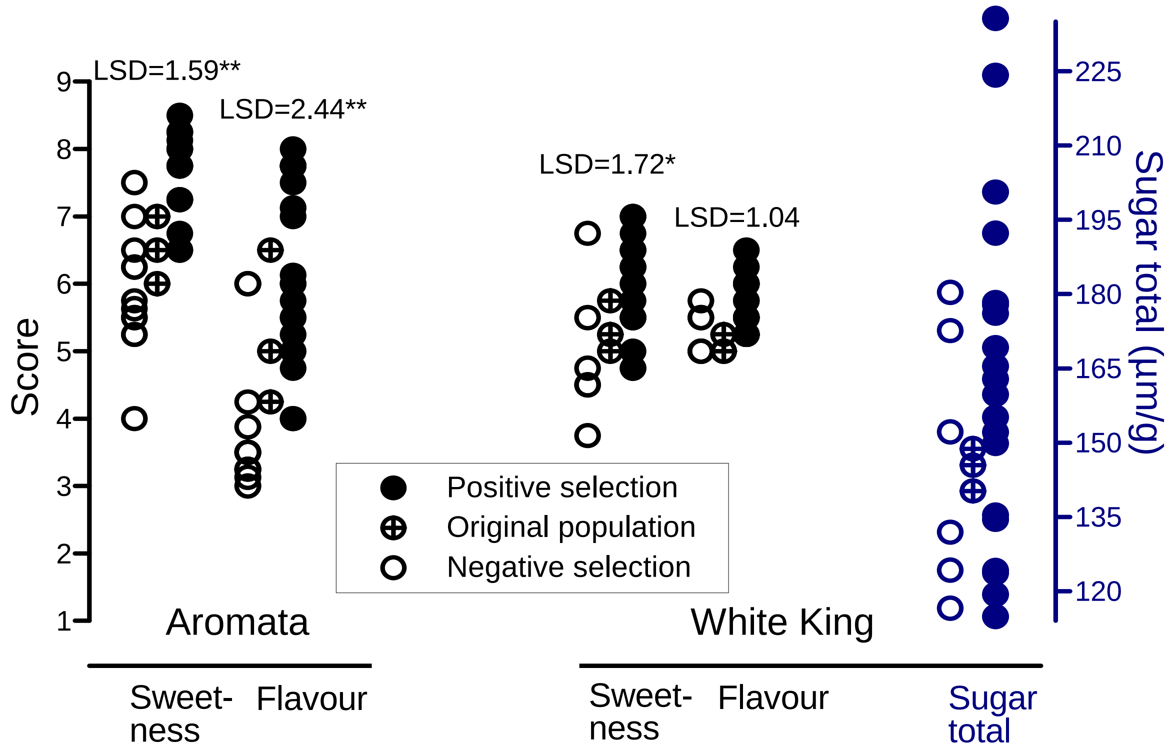
Fig. 4. Cross-over genotype x environment interaction in barley: Yield of lines selected in high and low yielding environments, respectively and then tested in 21 location-year combinations. The location-year combinations are combined in five groups according to the average grain yield of 64 barley lines (Ceccarelli 1996).

Other areas of excellence of organic breeding

Other important aspects like **participation in the breeding process, organoleptic quality**, and **site-specific adaptation** are not inherent to any of the production systems, but awareness is much higher in organic than in conventional agriculture. The priciples of organic agriculture – health, ecology, fairness, and care (IFOAM 2011 a) – include responsibility for **biodiversity,** present and future **genetic resources**.

Participatory rice breeding was developed in the Philippines by MASIPAG since 1987 (Medina 2009, Vicente et al. 2009). The objective was the creation of a seed system as an alternative to high input varieties propagated by the Green Revolution. Targeted at resource poor farming without chemical input, farmers identify the breeding objectives, are involved in producing crosses, select in segregating generations, evaluate and maintain the best populations. MASIPAG runs a central backup station, regional backup stations, and regional test farms. Presently more than 35,000 farmers in 47 provinces use regionally adapted selections.

An organoleptic quality assay was developed in a small organic breeding program with parsnip (*Pastinaca sativa* L.), a neglected root vegetable of temperate regions (Horneburg et al. 2009). In a first step individual plants were selected within two varieties for organoleptic quality by a technique developed in the project. The procedure allows harvesting seeds from the tested (and tasted!) plant. In a second step, progenies of positive- and negative-selected plants were compared with the original population. Organoleptic quality was scored and sugar content was analysed (Fig. 5). Organoleptic selection significantly improved sweetness, flavour, and sugar content. As a result the best quality variety was put on the market.



Each circle represents one progeny.

Differences between progenies * significant at p<0.05, ** significant at p<0.01
Sugar total = Glucose, fructose and sucrose

Fig. 5. Quality improvement of parsnip by one generation of organoleptic selection (Horneburg et al. 2009, modified).

Site-specific adaptation indicates that populations selected at a specific location are at this location superior in yield to populations selected at other locations. Almekinders et al. (2007) distributed early segregating generations of *Phaseolus* bean crosses to five farmer breeders in Nicaragua. All got the same 15 progenies and selected during five generations for disease resistance, plant architecture, yield, drought stress tolerance, and culinary quality. The resulting best selection from each farm was tested on all five farms. The results given in Table 1 indicate that in four out of five cases the selection originating from the test site outperformed the other four selections and the test variety. A similar result was demonstrated with lentil landraces by Horneburg and Becker (2008b).

Table 1. Yield (kg/ha) of five farmer selected bean populations at all five selection sites (Almekinders et al. 2007, modified).
One line represents one test site. The highest yielding selection is indicated **in bold**.

Test site		Selection site						*Mean*
	Altitude	Santa Rosa	Paso Hondo	La Lima	El Rosario	Rio Abajo	Test variety	
Santa Rosa	850 m	2005	1551	**2717**	2069	2127	1875	*2057*
Paso Hondo	630 m	969	**2522**	2134	2134	2263	1616	*1940*
La Lima	1000 m	969	839	**1948**	1098	1164	1551	*1262*
El Rosario	650 m	1035	1016	1180	**1722**	1275	1057	*1214*
Rio Abajo	600 m	2328	1616	1357	1482	**2522**	2269	*1929*
Mean		*1461*	*1509*	*1867*	*1701*	*1870*	*1674*	

Intrinsic value of plants

The organic movement values the plant as an integral being. Its integrity exists aside from the economic value of the species. Organic plant breeding respects the integrity of plants by respecting their natural reproductive ability and barriers, and their relationship with the living soil (Lammerts van Bueren et al. 2003).

Present and future sources for organic breeding

In the Central European Organic Outdoor Tomato Project the importance of **genetic resources from organic seed savers** became obvious (Horneburg and Becker 2008a). The main screening and breeding locations were three organic market gardens. Additionally a smaller number of genotypes were tested at up to 34 locations per year in amateur-, market-, and botanical gardens as well as in research institutions. After three years of evaluation, 88% of the best performing 33 varieties had originally been provided by non-commercial sources, i.e. genebanks, NGO and private seed savers. More than 60% were originally maintained / selected and recommended by seed savers and NGO within organic horticulture (Fig. 6). These findings also highlight ex situ conservation and dynamic conservation on farm as complementary systems.

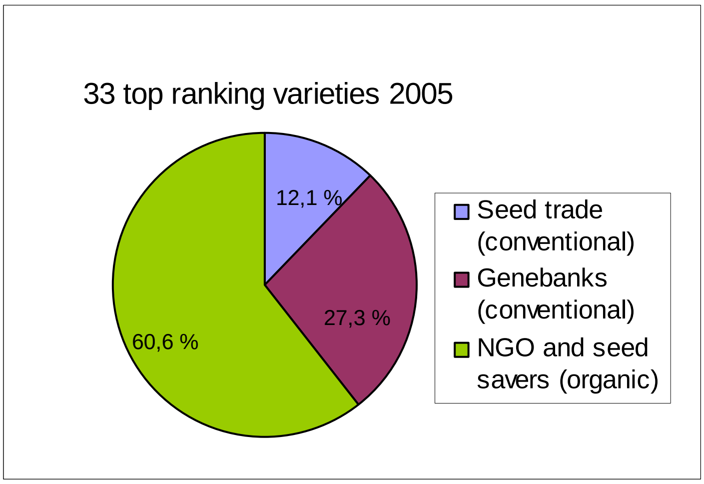


Fig. 6. Origin of the best performing organic outdoor tomato genotypes based on 3,500 accessions after 3 years of screening at 3 locations in Central Europe (data from Horneburg and Becker 2008a).

Organic breeders should make use of all genotypes available, as long as their use is in accordance with the regulations for organic agriculture. The breeders of Sativa / Switzerland had to rely on recent hybrid varieties to develop an open pollinated supersweet sweetcorn variety (personal communication F. Ebner). The supersweet genetics, reducing sugar transformation during shelf life, had so far exclusively been used in hybrid breeding. To “dehybridize the hybrids (Deppe 2000)” they used about 30 commercial hybrid varieties in multiple crosses and subsequent pedigree and mass selection. An additional variety had to be deleted due to contamination with GMO. Already after four cycles of selection 95% of the yield level of the hybrid varieties was attained (Fig. 7).

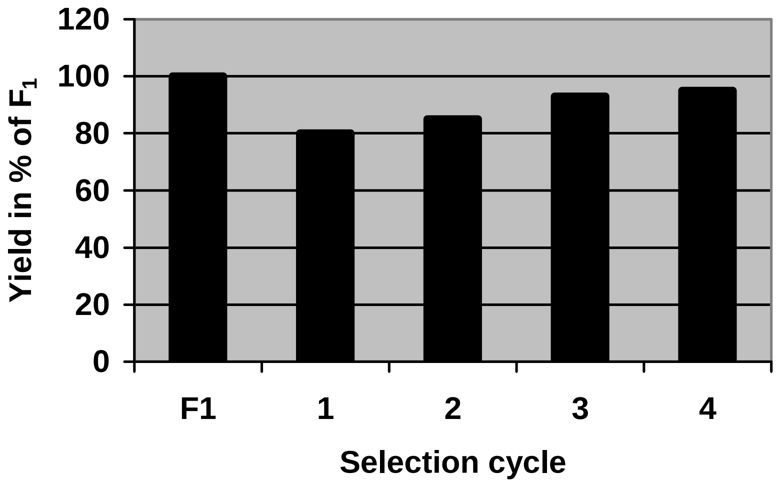


Fig. 7. Yield development during the selection for an open pollinated sweetcorn variety compared to the performance of hybrid varieties (F_1) (personal communication Sativa).

Open pollinated varieties create an open access source for further development. Hybrid varieties contribute very little to future genetic resources, because they are only in exceptional cases stored in genebanks or taken into dynamic development on farm, due to the segregation in the F_2-generation (Horneburg 2010). Patenting, non restored cytoplasmatic male sterility, gene technology incl. terminator technology, etc. further reduce the availability of future genetic resources.

Outlook

It is an open question whether **breeding for organics** (varieties bred in conventional agriculture tested in organics) or **breeding within organics** will be the main approach of the future. Especially the biodynamic movement has taken steps to foster organic breeding within organics and make the breeding process transparent to the public. Accordingly to my knowledge the first and only certification system for organic varieties was established by Demeter Germany (abdp 2011). IFOAM had to “Complete work on the draft plant breeding standards as soon as possible with the view of adopting them as IFOAM (certification) standards (Motion 26.2, IFOAM 2008)”. The topic was brought in to the IFOAM Standard for Organic Production and Processing (IFOAM 2011 b).

A controversial issue is the **use of hybrid varieties** and special techniques involved in hybrid breeding. The IFOAM General Assembly 2008 at Vignola / Italy carried motion 15.3 “to encourage the use of seeds within organic systems that are bred and maintained using open pollination and natural pollination techniques” and motion 26.1 “that cell fusion, including protoplast and/or cytoplast fusion breeding techniques, do not comply with the principles of Organic Agriculture. Therefore we urge the IFOAM World Board to develop clear guidelines on how to deal with varieties derived from cell fusion [...] (IFOAM 2008)”.

The “IFOAM Position on the Use of Organic Seed and Plant Propagation Material in Organic Agriculture” was approved by the World Board recently (IFOAM 2011 c). Aims like more independence from the market dominating companies, improving the legal situation, and advocacy for breeder exemptions and farmers’ privilege need a lot of coordinated input to improve the present situation.

How do we choose the **optimal selection environment**? In most organic breeding projects the selection is carried out within practical organic agriculture. Thus, the breeding approaches are well aimed at the target environment. Conventional formal and company breeding projects still frequently work at higher input levels. To be able to chose or create the optimal organic selection environment we need to gain a much better understanding of the interactions within the entire agricultural biocoenosis including the actions and interactions of biotic and abiotic stress conditions, soil biota – plant interactions, crop rotation, livestock, and cultivation practices. We need to investigate observations that selection in a sub-optimal environment may lead to improved performance in more favourable environments (Horneburg and Becker 2008a).

In some crops closing the **gap in performance between recent hybrids and traditional varieties** is a demanding task.

For the next three years and to the OWC 2014 I want to propose

- sessions for the exchange between organic plant breeders, and the
- creation of new cooperative projects in organic breeding and breeding research.

The encouraging results given in the preceding sub-chapters support the need for a much greater number of state of the art organic breeding projects. We have to bear in mind, though, that not every practical breeding approach and every breeding research project will give such positive or apprehensive output as in the examples shown above. Not using the opportunities offered by organic breeding, however, would be careless in a world with one billion starving and a growing demand for food and feed. Organic breeding has a great potential to create spin-off effects for other forms of agriculture!

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