YIELD AND QUALITY OF WHEAT CULTIVARS IN ORGANIC AND CONVENTIONAL FARMING SYSTEMS – – IS THERE AN INFLUENCE OF THE BREEDING HISTORY?

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Introduction

Organic farmers often use the same wheat cultivars as conventional farmers. Most of these cultivars have been bred under high-input conditions. Organically managed soils frequently do not deliver enough nutrients and fertilizers are limited. Therefore cultivars bred under high-input conditions often cannot perform to the full extent of their high genetic potential. Better nutrient uptake efficiency would be of great value for organic farms and conventional farms, producing under low-input conditions. Studies with winter wheat showed that cultivars, selected directly under organic conditions finally yielded higher under organic conditions than cultivars selected under conventional conditions [1], indicating a successful adaptation to low-input conditions during selection.

Nitrogen (N) and phosphorus (P) are usually the most limiting macro-elements in organic farming. A large part of P in soils is secluded in minerals and organic compounds, or heavily absorbed, and the supply of soil-N by mineralization is limited. The AMF symbiosis can positively influence plant growth and health. AMF are known to be strongly affected by the concentrations of soluble nutrients, specifically P, and also by plant genotype. This suggests a suppression of the AMF symbiosis with wheat cultivars obtained in selection programmes under high-input conditions. In addition, physiology and rooting of such cultivars may be adapted to high soil nutrient content. New cultivars may have a negative influence on AMF root-colonisation due to resistance introduced against fungal root pathogens.

A challenge for breeding for organic farming is to provide cultivars with high yields and an appropriate baking quality under limited conditions of organic fertilizer input. Our hypothesis was that cultivars bred under low-input conditions (old and organically bred cultivars) would perform better in organic low-input systems than conventionally bred cultivars, due to an adaptation to low-input conditions during the breeding process. It is in line with the opinion of Wolfe *et al.* [2], who recently defined the desired properties of wheat cultivars for organic agriculture. A better functioning of the AMF symbiosis could be one reason for a better adaptation. Our aim in this project was to assess yield and nutrient acquisition potential of the cultivars. Moreover, we want to identify the role of AMF on nutrient uptake and plant growth.

Review of the science

To be successful in organic farming, cultivars have to cope with some unfavourable conditions typically linked to organic farming, e.g. the low soil nutrient status due to the slow release of organic fertilizers, pressures from weeds as well as pests and diseases. Generally wheat yields are lower under organic than under conventional conditions [1,3-8]. Problems with weeds [9] and diseases but especially the lower input of nutrients [1,10] are the main reasons.

Wheat yield worldwide increased rapidly, especially during the second half of the last century due to an increased use of chemical fertilizers, and pesticides [11] and the introduction of semi-dwarf cultivars [12]. Wheat breeding was targeting the improvement of nutrient use efficiency, especially of N and P. Little is known about the influence of the nutrient level during breeding on the performance of cultivars under low- and high-input conditions. Brancourt-Hulmel *et al.* [13] assessed the efficiency of low- *vs*. high-input selection environments to improve wheat for low-input conditions. They concluded, that breeding programmes targeting low-input environments should include low-input selection environments to maximise selection gains. Results in barley could show a genotype x environment interaction. High-yielding lines selected in high-yielding environments showed lower yields on farmers' fields [11]. For organic wheat production it was shown that selection under organic conditions led to higher yields under organic growth conditions [1]. Beside yield, baking quality is the most important trait for bread wheat breeding. L-Baeckstrom *et al.* [10] found clear differences in baking quality between organically and conventionally grown wheat with higher baking quality in the conventional system. In that ten-year study, limited conditions of nitrogen (N) in the organic systems caused most of the differences.

Symbiotic relationships of wheat and AMF can play an important role for growth and productivity. There is clear evidence, that AMF colonization is affected by nutrient supply and AMF infection potential of the soil, as it has been shown in pot trials for P [14]. Highest values for shoot and root weights of wheat were measured for inoculated treatments in a pot trial with a soil low in P [15]. AMF symbiosis can lead to an increased uptake of P by plants. AMF hyphae could contribute up to 50-80% of total plant P-uptake in pot trials with wheat [16]. AMF occurrence and diversity show a strong dependence on the land use management. AMF root colonization in the DOK-trial decreased with increasing farming intensity. Colonization was highest in the unfertilized control and 30-60% higher in the organic than in the conventional farming systems. Similar results were found in additional pot experiments with field soils from the DOK-trial [17]. The results agree with Covacevich *et al.* [18], where AMF colonization was highest in plants receiving no annual P supply compared to plants grown at elevated nutrient levels. Native AMF could contribute considerably to the P-uptake of field grown wheat, even at typical soil fertility levels [19]. Oehl *et al.* [20] compared the influence of low-, moderate- and high-input conditions on AMF occurrence and diversity. Numbers of spores were highest under low- and moderate conditions. A shift in the AMF diversity could be shown with highest species numbers in the organic field, which was part of the DOK system comparison.

Wheat cultivars differ in their ability to form AMF symbiosis [21]. There is evidence that wheat cultivars bred before 1900 and the beginning of the intensive chemical fertilization were more responsive to AMF than modern cultivars [22]. Hetrick *et al.* [23] found a relationship between AMF root colonization and biomass only in responsive wheat cultivars. Results from the DOK-trial also showed that older wheat varieties might have a higher capacity to take up P: Grains of an old wheat variety had a distinctly higher P-content than grains of two recently released varieties, suggesting wheat x cultivar x AMF interactions [4].

Methods

DOK long-term experiment

A field experiment with ten winter wheat cultivars was performed in the DOK-trial with organic and conventional land use management [3] in 2006/2007. The DOK long-term trial was set up in 1978 at Therwil (7°33'E, 47°30'N) in the vicinity of Basle, Switzerland, by Agroscope Reckenholz-Tänikon Research Station and the Research Institute of Organic Agriculture (FiBL, Frick) comparing two organic (bio-Dynamic and bio-Organic) and two conventional farming systems ("Konventionell" with and without manure). The soil is a haplic luvisol (sL) (typic Haludalf) on deep deposits of alluvial loess. The climate is relatively dry and mild with a mean precipitation of 785 mm per year and an annual mean temperature of 9.5°C. The seven-year crop rotation was the same for all systems and from 1999 - 2006 the following crops were planted: potatoes, winter wheat 1, soybean, maize, winter wheat 2, grass-clover 1, grass clover 2. In the conventional system, pesticides were only applied if economic thresholds for pests and diseases were exceeded according to the integrated scheme of plant protection. In the organic farming systems plant protection was conducted according to the bio-dynamic guidelines. The field experiment is designed as a randomized block design with four replicates.

For our experiment ten cultivars were tested in two organic systems (BIODYN 1 and 2), a conventional system (CONMIN) and an unfertilized control (NOFERT). These systems differed mainly in fertilization strategy and plant protection. The organic systems stand for mixed farms with arable land and livestock, CONMIN for a stockless conventional system. Level of fertilization increased gradually from NOFERT to BIODYN 1 (0.7 livestock units ha^{-1}), BIODYN 2 (1.4 livestock units ha^{-1}) and CONMIN [24] resulting in higher phosphorus (P) and potassium (K) contents in the conventional system, when compared to the organic systems (Table 1).

Table 1.- Soil acidity, soil organic carbon content and soluble mineral elements in the soil at the beginning of the experiment in December 2006 (0-20 cm soil depth, means, (n = 32). Within columns, different letters indicate differences based on a least significant difference test ($p < 0.05$)

System	pH $[H_2O]$	C_{org} [%]	N_{min} [a] [kg ha^{-1}]	P [b] [mg kg^{-1}]	K [b] [mg kg^{-1}]
NOFERT	5.84 c	1.11 c	27.55 c	8.30 c	13.65 d
BIODYN 1	6.14 b	1.22 b	32.26 b	8.68 c	24.23 c
BIODYN 2	6.40 a	1.41 a	40.90 a	12.99 b	34.51 b
CONMIN	6.34 a	1.23 b	31.95 b	24.45 a	39.95 a

[a] $N_{min} = NO_3 - N + NH_4 - N$ [b] measured in a double lactic acid extract

Winter wheat cultivar experiment in the DOK trial and selected cultivars

Old, organically and conventionally bred cultivars selected between 1840 and 2006 were sown in the trial - in total nine cultivars and one composite cross population (Table 2). In the composite cross population (CCP) a large number of cultivars from the UK were intercrossed and propagated as one bulk [25]. All cultivars had to be of bread wheat quality and suitable for the growing conditions given in North Western Switzerland. The old cultivars (Rouge de Bordeaux, Mont Calme 245 and Probus) were selected and released before 1950 and represent the era before the intensification in agriculture. The cultivars named as “organically bred” (Scaro, Sandomir and CCP) derived from breeding programs conducted within organic agriculture, i.e. all breeding steps were carried out on organically managed sites. Moreover, selection and propagation techniques are conforming to organic principles. Therefore these cultivars can be called “directly selected for organic farming” according to the definitions on organic breeding of Wolfe et al. [2] Conventionally bred cultivars (Titlis, Caphorn, Antonius and DI 9714) originated from breeding programs for conventional agriculture. Cultivars Titlis and Antonius are also recommended cultivars for organic farming in Switzerland [26]. Four Swiss cultivars – adapted to the local conditions (Mont Calme 245, Probus, Titlis and Scaro) represent the development of wheat breeding in Switzerland during the last century.

Cultivar	Country of origin	Year of release	Origin/Breeder
Old cultivars and landraces			
Rouge de Bordeaux	FR	1840	L'Institut National de la Recherche Agronomique (INRA), F-75338 Paris
Mont Calme 245	CH	1926	National gene bank ACW Changins, CH-1260 Nyon 1
Probus	CH	1948	National gene bank ACW Changins, CH-1260 Nyon 1
Organically bred culitvars			
Scaro	CH	2006	Sativa Rheinau AG, CH-8462 Rheinau, Getreidezüchtung Peter Kunz, CH-8634 Hombrechtikon
Sandomir	DE	not registered	Getreidezüchtung Darzau, Karl Josef Müller, DE-29490 Neu Darchau
Composite Cross Population	GB	not registered	The Organic Research Center, Elm Farm, GB-Hamstead Marshall, Newbury, Berkshire RG20 0HR
Conventionally bred cultivars			
Titlis (standard)	CH	1996	Delley seeds and plants, CH-1567 Delley / National gene bank ACW Changins, CH-1260 Nyon 1
Antonius	AT	2003	Delley seeds and plants, CH-1567 Delley/ Saatzucht Donau Ges.m.b.H. & CoKG, 2301 Probstdorf
DI 9714	FR	not registered	L'Institut National de la Recherche Agronomique (INRA), FR-75338 Paris
Caphorn	FR	2001	Delley seeds and plants, CH-1567 Delley

Figure 1.- Selected winter wheat cultivars and their country of origin and year of release

Winter wheat cultivars were sown after maize on the 26.10.2006 in ten marginal subplots in 16 DOK-plots (5 m x 20 m, four land use systems each with four replicates) in the described four systems and in all four replicates, resulting in 160 subplots (3 m x 1 m). Plots of BIODYN 1 were adjacent to BIODYN 2, plots of NOFERT adjacent to CONMIN. Sowing density was 420 germing seeds m^{-2} according to organic farming recommendations. Seed density was the same in all systems and for all cultivars as recommended for cultivar tests [27]. The seed number was adjusted according to the results of a previous germination test. Germination of the cultivars ranged from 92% to 98%. Row distance was 16.7 cm. The cultivars were distributed randomly in each replicate of the DOK-experiment.

The field experiment aims to observe different agronomic growth and harvest parameters, nutrient uptake and the occurrence of AMF symbiosis during the growing season. At the beginning of the experiment, soil parameters were analysed and the number of AMF spores were counted. Samples of roots (soil core Ø 4 cm, 20 cm deep) and shoots were taken at tillering and flowering to measure nutrient uptake and for AMF assessments. During the growing season plant density was counted, plant length measured, plant growth stages, pests and diseases were recorded. Harvest took place at the end of July. We analyzed yield of grain and straw, yield components such as thousand kernel weight and hectolitre weight. A rough estimation of the baking quality of wheat was done analyzing relevant parameters such as grain crude protein content, Zeleny value, Hagberg falling number and total gluten content and the corresponding gluten index. Moreover, we analysed macro-and micro-nutrients in shoots, grain and straw to trace the relocation of nutrients.

On the conference we present results of grain yield, grain protein content, a redundancy analysis of yield and quality parameters as well as results of mycorrhizal assessments.

Results and discussion

<u>Grain yield and grain crude protein</u>

Systems and cultivars affected yields of grain and straw significantly, whereas no significant genotype x environment interactions were detected in a two-way ANOVA. Higher N-input rates within the systems resulted in higher yields. Yields in the conventional system CONMIN were higher than in the organic systems. Across all cultivars, grain yield was 62% higher in the conventional system CONMIN than in the organic system BIODYN 2. An increasing trend of yields was observed along year of release of cultivars. Conventionally bred cultivar Antonius achieved highest yields across all systems and 29% more than the overall yield of the oldest cultivar Rouge de Bordeaux. Our results did not show that cultivars bred under low-input conditions (old and organically bred cultivars) yielded higher under low-input conditions - in contrast to other studies on wheat [1,13] or on barley [28] A contradictory situation was found for conventional conditions, where conventionally bred cultivars yielded higher compared to old and organically bred cultivars. An explanation for these contradictory results may be that the deep Loess soil at the DOK experiment site has a high inherent soil fertiliy, good water retention and little weed pressure.

Grain crude protein contents were highest in the conventional system CONMIN due to the use of mineral fertilizers. In the unfertilized control NOFERT grain protein was high due to low numbers and weights of grains. Grain protein was 23% lower in the organic system BIODYN 2 than in system CONMIN. Grain protein increased with nutrient input in agricultural systems. Across all systems the old cultivars achieved significantly higher grain protein contents than organically and conventionally bred cultivars. Along year of release the old cultivar Probus achieved the highest grain protein contents, the conventionally bred cultivar Caphorn the lowest. These results are in good agreement with studies of several authors [29-32]. In BIODYN 2 as well as in CONMIN organically bred cultivars achieved slightly but not statistically significant higher protein contents than conventionally bred cultivars.

Results of a redundancy analysis for grain yield and yield components showed clearly that yield and yield components were mainly influenced by systems, which means by nutrient input, while cultivars played a minor role. In contrast quality was mainly determined by cultivars and hardly affected by nutrient input.

AMF root-colonization

AMF root-colonization was decreasing within nutrient input in root samples taken at tillering as well as at flowering stage and highest in the organically managed system BIODYN 2. Lowest values were measured at tillering in the conventional system CONMIN and at flowering in the unfertilized control NOFERT. We could not observe statistically significant differences in AMF-root colonization between the ten cultivars. Our data did not indicate that breeding conditions influenced AMF-root colonization of cultivars.

Conclusion

Our data shows that winter wheat cultivars and systems affected yield and quality parameters significantly. Under conventional farming conditions, yields strongly increased along year of release of cultivars, while the same set of cultivars showed only a minor increase under organic farming conditions. The results imply that breeding for yield was successful during the last century but only under high-input conditions, where the development was accompanied by rising inputs of external resources such as mineral fertilizers. Under organic low-input and nutrient-limited conditions, modern cultivars could not perform to the full extent of their genetic potential, irrespective if the breeding took place under conventional or organic farming conditions. Organic farming aims to maintain a resilient system in the soil to produce healthy products without exploiting natural resources. But beside aspects of environment protection, product safety and quality, organic agriculture has to make efforts to risen yields to cope with the challenge of food supply. Rising yields would moreover improve the economical situation for organic farmers. We suggest that modern breeding should focus for acceptable protein contents also under low-nitrogen input. First results on mycorrhizal colonization did not show that there was an influence on the AMF-symbiosis of wheat cultivars during breeding the process or by the breeding conditions. Further AMF assessments are ongoing on three different sites in Switzerland on less fertile soils. Theses assessments will show whether abiotic stress factors such as low precipitation or poor soil conditions will lead to cultivar x environment interactions.

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