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"Productivity, quality and sustainability of winter wheat under long-term conventional and organic management in Switzerland"

Jochen Mayer[a,*], Lucie Gunst[a], Paul Mäder[b], Marie-Françoise Samson[c], Marina Carcea[d], Valentina Narducci[d], Ingrid K. Thomsen[e], David Dubois[a]

[a] Agroscope, Institute for Sustainability Sciences ISS, Reckenholzstrasse 191, CH-8046 Zurich, Switzerland
[b] Research Institute for Organic Agriculture, Ackerstrasse, CH-5070 Frick, Switzerland
[c] INRA, UMR1208 Ingénierie des Agropolymères et Technologies Emergentes, F-34060 Montpellier, France
[d] Consiglio per la Ricerca e la Sperimentazione in Agricoltura–Centro di Ricerca per gli Alimenti e la NUTrizione (CRA-NUT) (Agricultural Research Council – Research Center on Food and Nutrition–CRA-NUT formerly INRAN), via Ardeatina 546, I-00178 Rome, Italy
[e] Department of Agroecology, Aarhus University, P.O Box 50, DK-8830 Tjele, Denmark

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ABSTRACT

Long-term sustainability and high resource use efficiency are major goals for high quality baking wheat production throughout the world. Present strategies are low input systems such as organic agriculture or improved conventional systems (integrated). The fertilisation level and strategy, crop protection as well as preceding crop effects may modulate system performance with respect to wheat grain yield, quality and environmental performance of the systems.

Our aim was to evaluate data of winter wheat (*Triticum aestivum* L.) performance from the DOK long-term systems experiment in Switzerland comparing two mixed organic (biodynamic and bioorganic: BIODYN and BIOORG) and a mixed conventional cropping system (CONFYM) using mineral fertilisers and farmyard manure at two fertilisation intensities (level 1: 50% of standard fertilisation, level 2: standard fertilisation) since 1978. A conventional system was fertilised exclusively minerally at level 2 (CONMIN) and a control remained unfertilised (NOFERT). We compared crop yields, baking quality parameters, the nitrogen use efficiency and the effect of maize and potatoes as preceding crops obtained between 2003 and 2010 along with long-term soil sustainability parameters.

The mean grain yields across both fertiliser levels of the organic cropping systems (BIODYN and BIOORG) were 64% of CONFYM, whereas crude protein contents were 79% of CONFYM at fertilisation level 2 and achieved 90% at level 1. The main driving factor of lower yields was a reduction of the numbers of ears per m^2 and the thousand kernel weight. The apparent nitrogen use efficiency decreased with increasing N fertilisation. Doubling the organic fertilisation in the organic systems only slightly improved wheat grain yields but was not able to improve grain baking quality, due to low mineral N additions via slurry and farmyard manure. In contrast the effects of the preceding crop potatoes in comparison with preceding silage maize outperformed the organic fertilisation effects, resulting in 33% higher yields and 11% higher crude protein contents. The yield components recorded in the case of preceding potatoes demonstrated a more synchronised nutrient supply throughout the wheat development. Over all low input systems and both fertilisation levels in the conventional mixed farm system at half standard fertilisation (level 1) performed best with distinctly higher grain yields and crude protein contents than in the organic systems with standard fertilisation. However, all systems, organic and conventional, with the low or zero organic fertiliser inputs performed poorly considering the long-term soil quality parameters, indicating a degradation of soil quality. The DOK long-term experiment allows an integrated view on the performance of baking wheat production and long-term sustainability. The results emphasise the importance of a sufficient supply of soils with organic fertilisers as well as the need to improve the availability of organic nitrogen and synchrony between nutrient supply and demand in organic baking wheat production, beside the selection of a suitable preceding crop.

* Corresponding author. Tel.: +41 584687214; fax: +41 584687201.
E-mail address: jochen.mayer@agroscope.admin.ch (J. Mayer).

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1. Introduction

Feeding a growing human world population is one of the main challenges in the 21st century. Restricted land for agricultural cultivation and restricted natural resources force us to increase the productivity per area with lower external inputs. Enhancing resource use efficiency without negative effects on crop quality and system sustainability is therefore, the main aim for agricultural development. The two major strategies are low input systems such as organic agriculture or improved conventional 'integrated' systems. With a production of 201 million tons, wheat (*Triticum aestivum L.*) is the most important cereal in Europe and, at 651 million tons, the third most important worldwide (FAO, 2012). Hence, a better understanding of the effects of different management practices on grain yields, grain quality, resource use efficiency and management sustainability are essential for future wheat production.

Nitrogen (N) supply in organic agriculture systems relies mainly on organic soil nitrogen indirectly provided by inputs through legumes in the crop rotation or by recycling N through solid or liquid manure (Berry et al., 2002). N inputs by manure are limited in organic agriculture systems by the EU regulation EC No. 834/2007 to a maximum of 170 kg N ha^{-1} per year (EC, 2008). N in legume crop residues as well as major fractions in manures are organically bound and must be mineralised in soil prior to becoming available to plants. The production of high baking quality winter wheat is mainly restricted by the mineralisation dynamics of the soil organic matter under specific site conditions during tillering/stem elongation and grain filling stages (David et al., 2005; Hildermann et al., 2009; Rieger et al., 2008). Bread wheat from organic systems often does not meet the quality requirements of industrial bakeries. In contrast, integrated conventional production systems aim to achieve moderately high grain yields and a good baking quality with an optimised fertilisation combined with reduced applications of herbicides and fungicides (Jordan et al., 1997). In such systems plant nutrients, mainly N, can be applied more in synchrony with the demand of the crop and it is possible to control grain yield and grain baking quality more precisely. In general, under European site conditions, grain yields of organic agriculture wheat achieve 30–70% of conventional production (David et al., 2012) and crude protein contents, as a rough parameter for the grain baking quality, are 77–94% of conventional ones (Carcea et al., 2006; Hildermann et al., 2009; Krejcirova et al., 2007; Mäder et al., 2007).

Different management strategies between organic and conventional farming systems and within the systems have distinct effects on parameters related to long-term system sustainability. Differences were found in soil carbon (Fliessbach et al., 2007; Gattinger et al., 2012; Kong and Six, 2010; Leifeld et al., 2009) and N stock development (Bosshard et al., 2009), available nutrients (Keller et al., 2012; Oehl et al., 2004a) as well as in soil microorganism abundance and biodiversity, soil fauna and weed biodiversity (Dubois et al., 1998; Esperschüetz et al., 2007; Fliessbach and Mader, 2000; Gunst et al., 2013; Hiltbrunner et al., 2008; Oehl et al., 2004b). Energy and nutrient use efficiency may differ, lower input systems in many cases having advantages over high input systems (Nemecek et al., 2011).

In this study we aimed to evaluate data on winter wheat performance from 2003 to 2010 from the DOK long-term systems experiment in Switzerland comparing organic and conventional cropping systems since 1978 at two fertilisation intensities on a loess soil. We examined (i) the effects on winter wheat grain yields, crude protein contents and nitrogen fertiliser use efficiency, (ii) the related interactions on yield components and (iii) the effects on wheat baking quality parameters in bio-organic and bio-dynamic cropping systems. In addition, we compare the results with long-term soil sustainability parameters from the DOK experiment and discuss them with respect to the aim of long-term sustainable land use.

2. Materials and methods

2.1. The DOK experiment

In 1978 the DOK field experiment, comparing two organic (bio-dynamic and bio-organic) and two conventional agriculture systems ("Konventionell" with and without manure), was set up at Therwil (7°33′E, 47°30′N) in the vicinity of Basle, Switzerland. The four farming systems mainly differed in fertilisation strategy and plant protection (Table 1). Crop rotation changed slightly at the end of each rotation period but was identical for all systems (Besson and Niggli, 1991) and, except for the more frequent mechanical weeding in the organic plots, this was also true for soil tillage.

The bio-organic system (BIOORG) is managed according to the guidelines of BioSuisse (BioSuisse, 2012) and the bio-dynamic (BIODYN) system according to the Demeter Suisse guidelines (Demeter-Schweiz, 2012). The conventional systems with mineral fertilisers plus farmyard manure (CONFYM) and with mineral fertilisers alone (CONMIN) have been managed in accordance with the Swiss integrated management standard since 1985 (IP-Suisse, 2007). As a control, an unfertilised treatment (NOFERT) was included in the design. The BIOORG, BIODYN and CONFYM systems represent mixed farms with livestock housing (milk cows) and arable land receiving farmyard manure (FYM) and slurry. These systems were split into treatments with two fertilisation levels. Level 2 corresponds to a standard fertiliser input of 1.4 livestock units (LU), which is an average value for organic farms, and level 1, corresponding to 0.7 LU or 50% of the fertiliser input of level 2. CONFYM additionally receives mineral fertilisers according to the Swiss national fertilisation guidelines (Flisch et al., 2009), whereas CONMIN receives only mineral fertilisers at level 2 (Table 1).

The organic systems (BIODYN and BIOORG) received 60–65% of the nutrients (NPK) that were applied to the conventional mixed systems (CONFYM) (Mäder et al., 2002; Niggli et al., 1995). The organic fertilisation was performed with system specific manure types. CONFYM received stacked FYM, BIOORG rotted FYM and BIODYN composted FYM with biodynamic preparations (Table 1). The distribution of the manure and slurry in the rotation was also system-specific. In CONFYM, manure and slurry were applied only to potatoes, maize and grass/clover, while in the organic systems the winter wheat plots also received slurry and, partly, also FYM. The crop rotation comprises seven fields. The crops in the fourth crop rotation period from 1999 to 2005 were 1 clover-grass, 2 clover grass, 3 potatoes, 4 winter wheat, 5 soybean, 6 silage maize and 7 winter wheat. In the fifth period from 2006 to 2012, potatoes and silage maize were switched: the crop sequence was 1 clover-grass, 2 clover grass, 3 maize, 4 winter wheat, 5 soybean, 6 potatoes and 7 winter wheat.

The soil type of the site is a haplic luvisol on deep deposits of alluvial loess. It contains 12% sand, 72% silt and 16% clay. Soil organic carbon ranged between 9.4 g kg^{-1} in NOFERT and 13.1 g kg^{-1} in BIODYN2. (Table 7). Soil acidity was between pH (H_2O) 5.7 in NOFERT and 6.7 in BIODYN2. Plant available potassium (K) and phosphorous (P) concentrations (CO_2 extract) ranged between 3.2 (NOFERT) – 12.9 (BIOORG2) mg K kg^{-1} soil and 0.2 (NOFERT) – 1.2 mg (CONMIN2) P kg^{-1} soil, respectively (Table 7). The mean precipitation averages 785 mm and the mean annual temperature is 9.5° C.

The total experimental area (including grass service strips) measures 1.84 ha including 96 individual plots, each measuring 100 m^2 (5 m × 20 m). The field experiment is designed as a split-split-plot, latin rectangle with four replicates. Additionally each crop rota-