Organic World Congress 2020 | FRANCE

SEPTEMBER 21ST TO 27TH, 2020 IN RENNES
AT THE COUVENT DES JACOBINS • RENNES MÉTROPOLE CONFERENCE CENTRE
www.owc.ifoam.bio/2020

OWC 2020 Paper Submission - Science Forum

Topic 1 - Ecological approaches to systems' health

OWC2020-SCI-1328

THE MULTIFUNCTIONAL CHALLENGE OF FUTURE AGRICULTURE – ANSWERS FROM 40 YEARS DOK RESEARCH

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Preferred Presentation Method: Oral presentation

Full Paper Publication: No

Abstract: Achieving sufficient and stable crop yields with limited cropland and without excessive use of non-renewable resources under a changing climate are the multifunctional challenges of future agriculture. We compared the performance and sustainability of organic and conventional cropping systems in the DOK long-term systems comparison after 40 years of management. For the first time we present a comprehensive evaluation of the whole DOK design including the systems with reduced stocking rates. Yield, nutrient dynamic and soil quality evaluations show clearly the trade-offs between productivity and sustainability in organic as well as in conventional systems. Low input conventional systems reveal the best input-output performance but lowered soil quality; regular organic systems were most sustainable but achieved only moderate non-legume yields.

Introduction: Sufficient and stable crop yields are the basis for feeding a growing world population. Limited cropland, climate change, soil quality and biodiversity coupled with excessive use of non-renewable resources require new solutions for future cropping systems beyond existing management practices. Long-term cropping system comparisons give us a better systematic understanding of the performance of productivity and the provision of ecosystem services and their trade-offs in organic and conventional cropping systems. They allow us to give comprehensive answers on the multifunctional challenges of future agriculture.

Here we compare the yield performance and the nutrient use as well as sustainability indicators of organic and conventional cropping systems in the DOK long-term systems comparison after 40 years of management. For the first time we present a comprehensive evaluation of the whole DOK design including the systems receiving regular fertilisation representing typical Swiss agriculture and systems with reduced stocking rates.

Material and methods: In the DOK (bio-**D**ynamic, bio-**O**rganic, **K**onventionell) field experiment, located in Therwil south of Basle, Switzerland, organic and conventional cropping systems have been compared since 1978. The cropping systems mainly differ in fertilisation strategy and plant protection. Crop rotation changed slightly at the end of each rotation period but was identical for all systems. This was also true for soil tillage. The experiment comprises two organic systems, bio-organic (O) and bio-dynamic (D) and a conventional systems with mineral fertilisers plus farmyard manure (K) and with mineral fertilisers alone (M). As a control, an unfertilised treatment (N) was included in the design. The D, O and K systems represent mixed farms with livestock housing (dairy cows) and arable land receiving farmyard manure 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, which is an average value for organic farms in Switzerland, and level 1, corresponding to 0.7 livestock units or 50% of the fertiliser input of level 2. System K additionally receives mineral fertilisers according to the Swiss national fertilisation guidelines, whereas M receives only mineral fertilisers at level 2. The organic systems (O and D) received 60–65% of the nutrients (NPK) that were applied to the conventional mixed system (K). Systems K and M received pesticides for weed, pest and disease control. The crop rotation comprises seven fields. The crops in the present crop rotation period from 2013 to 2019 are 1 clover-grass, 2 clover grass, 3 maize, 4 soybean, 5 winter wheat, 6 potatoes and 7 winter wheat.

We evaluated the forty-year data series of yields, yield development and yield stability, phosphorous, potassium and nitrogen balances as well as soil carbon and nitrogen stock changes and trade-offs between management intensity and productivity in both organic and conventional systems.

Results: Mean yields of the organic systems O and D were lower than conventional systems K and M. Organic potatoes yields were 65 %, wheat 79% and clover-grass 88% of conventional. However, silage maize yields achieved 87% and soybean 100% of conventional. The conventional systems at fertilisation level 1 achieved higher yield compared to organic systems at full fertilisation level 2 (Fig. 1). Except for the unfertilized control (N) yields showed no significant negative trends. However, clover-grass yield tend to decrease in all treatments whereas potatoes and wheat yields tend to increase slightly. Yield stability indicated by the coefficient of variance was higher in the conventional systems for potatoes and clover-grass, but differed only slightly for wheat. Both conventional cropping systems have similar annual phosphorous inputs while phosphorous inputs in systems O and D are reduced by at least one third. Differences in phosphorous outputs between farming systems are less pronounced. Resulting phosphorous balances were positive (inputs higher than outputs) for cropping systems M and K, while they were negative for O and D. Potassium balances were equilibrated for organic and conventional systems at fertilisation level 2. However, at fertilisation level 1 balances were negative for both, phosphorous and potassium, and led to a decrease in soil available phosphorous and potassium. From nitrogen budgets opposing inputs via fertilization, symbiotic fixation, seeds and deposition to nitrogen outputs via harvested products resulting balances range from -20 kg to surpluses of about +50 kg N ha^{-1} yr^{-1}. Negative and equilibrated balances, however, indicate soil N mining, while surpluses point to a risk of N losses, and/or N accumulation in the soil (Fig. 2). Estimation of soil N stocks changes based on yearly total N concentration measurements suggest that soil N stocks in the topsoil decreased under~~ all~~ treatments at zero and fertilisation level 1 (N0, D1, O1, K1) and mineral fertilisation (M2). ~~except~~The ~~for the~~ N stocks increase in bio-dynamic system and were constant in bio-organic and conventional systems at~~on~~ fertilisation level 2. Trends of carbon stock changes were similar to nitrogen stock changes.

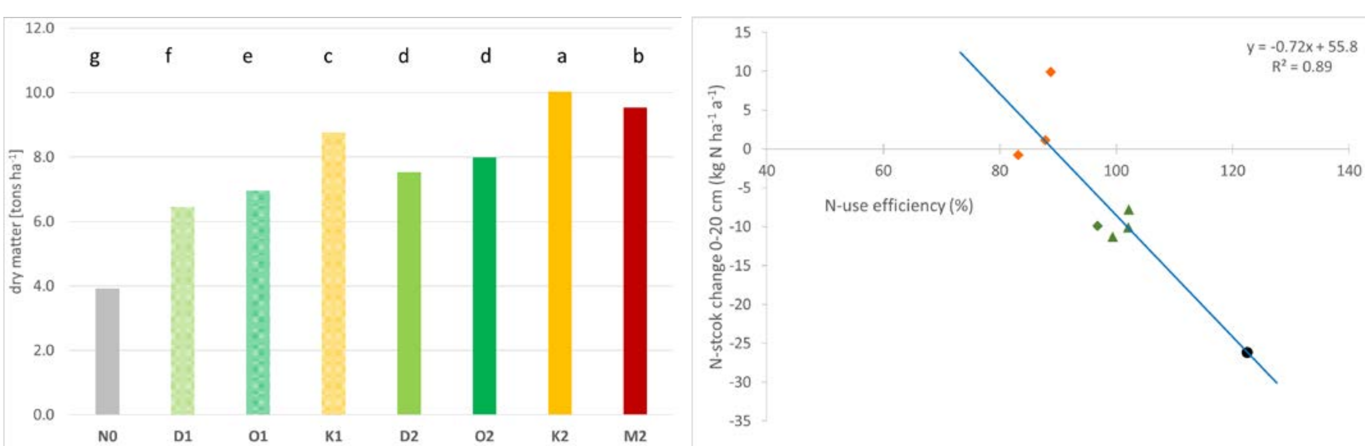

Fig. 2 Trade-offs between N-use efficiency of DOK systems at different fertilisation levels and soil quality indicated as N-stock change during 40 years of management

Discussion: Beside sufficient yield levels, a key question is how crop yield development performs in the long-term in different cropping systems. In addition, temporal yield stability is crucial for regional food security. Organic cropping systems show here, per unit yield, a 15% lower temporal static stability (Knapp and van der Heijden 2018). Fertilisation, mainly nitrogen, is the main driver for the yield gap between the systems. However, results from the DOK experiment show that for the yield level, crop protection and fertilisation was important, stability was mainly determined by crop protection and not by fertilisation. An evaluation of the yield gap clearly showed that a high gap was caused by lower organic yields and comparatively constant conventional yields.

Yield trend analysis in the DOK experiment reveal positive or stagnating trends in all systems for wheat and maize over a data series of 40 years. Surprisingly the clover-grass ley yields tended to decrease over time in all systems and at different fertilisation levels. Neither a significant increase nor decrease in yield gap between organic and conventional systems could be observed. This finding is confirmed by the yield trends in organic-conventional long-term comparisons (≥ 15 years), which show in most cases constant or slightly increasing yields under organic management (Mayer and Mäder 2016). However, also farm yields of wheat and maize under conventional management showed no positive yield development in regions with high yield levels like Central and North Europe since the 1990ies.

Trade-offs exist between the N-use efficiency of systems, which was calculated from the DOK N-budgets, and the development of soil quality. A high N-use efficiency close to 100% was in line with negative trends of soil N and C stock changes and in consequence losses of soil quality. From an N-use efficiency below 85% soil quality could being kept over time or being improved in the case of the bio-dynamic system (Fig. 2).

The future challenge will be to reduce the yield gap between organic and conventional systems by a substantial yield increase in organic systems without trade-offs between productivity and sustainability of agricultural management. The comparison of the regular fertilised mixed cropping systems in the DOK experiment with reduced fertilisation (50% of regular) clearly demonstrates the reasons for yield limitations of organic systems. The conventional system with reduced fertilisation gained higher or similar yields over all crops compared to the regular fertilised organic systems but it received less absolute amounts of nutrients with fertilisers. However, the conventional system received a higher amount of mineral nitrogen forms and it was treated with pesticides. Hence, the main drivers to reduce the yield gap are an improvement of nitrogen availability and a synchronisation between supply and crop demand. Further improvements in weed control by new technologies and crop protection by cultivars that are more resistant or by crop diversification will be a key measure of future management.

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Disclosure of Interest: None Declared

Keywords: Yields, yield stability, NPK-budget, nitrogen use efficiency, trade-off