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# Life cycle assessment of Swiss organic farming systems

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## Summary

The impacts of organic and integrated farming systems in Switzerland on the environment have been assessed in a comprehensive study by the life cycle assessment method. This paper reports a comparison of the treatments of the DOC experiment. Organic farming showed clear ecological advantages particularly for eco- and human toxicity, resource use and biodiversity. These ecological advantages only partly apply to nutrient losses and are not always found for single products. Per kg of organic product, higher impacts were often found for global warming potential, ozone formation, eutrophication and acidification compared to integrated production. In the same crop rotation with the same amount of organic fertilisers there were no systematic differences in soil quality of organic compared with integrated production. Further improvement of the environmental performance of organic farming should focus on achieving higher yields of good quality – especially in potatoes and cereals - by using inputs more efficiently and minimising nitrogen losses.

**Keywords:** Life cycle assessment, farming system, organic farming, integrated production

## Introduction

In the last few years the proportion of farms in Switzerland managed organically has increased considerably and is now over 10%. The expansion of organic agriculture is seen as one way to remedy some of the environmental problems caused by intensive agriculture. However, the environmental impacts of organic farming systems in Switzerland have not been systematically quantified to date. Therefore the impacts of integrated production (IP) and organic farming (OF) systems on the environment were examined in a comprehensive study of Swiss arable crop and forage production (Nemecek *et al*., 2005) using the life cycle assessment (LCA) method. This paper presents selected results from the evaluation of OF systems.

## Materials and Methods

Life Cycle Assessments were carried for i) the DOC long-term experiments, Northern Switzerland; ii) Burgrain long-term experiments, Central Switzerland; iii) model arable crops and iv) model forage production systems (Nemecek & Erzinger, 2005; Nemecek *et al*., 2005). In each part of the study, organic and integrated farming systems were compared; the system boundary was defined at the farm gate for arable crop products and at the manger for the forage systems. We carried out the analysis of the potential ecological impacts in respect of the productive function, the land management functio and the financial function of agricultural systems. The respective functional units were kg dry matter of harvested products or MJ net energy lactation for the first function, hectare of land managed during one year for the second function and Swiss franc gross profit for the third function. The LCAs were carried out using the SALCA methodology (Swiss Agricultural Life Cycle Assessment) developed by Agroscope FAL Reckenholz (Gaillard *et al*., 2006) and the ecoinvent database (Frischknecht *et al*., 2004). Direct emissions of ammonia, nitrous oxide, phosphorus and heavy metals as well as soil loss were calculated with models, considering management and situation-specific parameters (Gaillard *et al*., 2006). The impacts on soil quality and biodiversity were assessed by the newly developed SALCA methods (Oberholzer *et al*., 2006; Jeanneret *et al*., 2006).

The full results for all parts of the study are presented in Nemecek *et al*. (2005), this paper presents analysis of all eight farming systems in the DOC experiment for the second and third crop rotation periods (1985–1998). The DOC experiment is comparison of the bio-dynamic (D), bio-organic (O) and conventional/integrated (C and M) farming systems established in 1978 (Mäder *et al*., 2002). Within the conventional/integrated system an exclusively mineral fertilisation (M) is compared to mixed organic-mineral fertilisation (C). In addition three fertiliser levels are studied: normal levels (D2, O2, C2 and M2, which are substantially higher in conventional than in OF), 50% of the normal level (D1, O1 and C1) and no fertilisation (D0).

## Results

Demand for non-renewable energy resources in the farming systems (Fig. 1) is dominated by the use of machinery (mainly for soil cultivation and harvesting) and the manufacturing of mineral fertilisers (particularly synthetic nitrogen fertilisers). The OF systems D and O had a lower demand for energy resources per hectare, as they do not use mineral N fertiliser. The system M2, with mineral fertilisers only, consequently showed the highest energy demand. When analysed per kg harvested dry matter, OF systems proved to be significantly more favourable compared to system C (see Nemecek *et al*., 2005). Reducing the fertiliser level in conventional farming led to a slightly decreased energy demand, while the contrary was true in the organic systems. The plot D0 without fertilisation showed a higher impact per kg, which is explained by the low yield of this system. Due to the use of synthetic pesticides, the conventional system had higher ecotoxicity potentials than systems D and O.

The potential impacts of management on biodiversity (Table 1) were analysed only per hectare for methodological reasons (see Jeanneret *et al*., 2006; Nemecek *et al*., 2005). OF showed a higher biodiversity potential than conventional production for most indicator organism groups. This difference was mainly caused by the ban on synthetic pesticides in OF; copper was still used in system O for potatoes. Reduced fertilisation (D1, O1, C1) showed hardly any difference compared with the normal fertiliser levels (D2, O2, C2). Only the no-fertilisation plot D0 revealed a substantially higher biodiversity potential within the OF systems. Similar environmental advantages of OF systems were also observed in the farming system comparison experiment at Burgrain and for the model arable crops and forage production systems.

## Discussion

OF is clearly favourable for impacts related to resource consumption (energy and mineral resources), toxicity and biodiversity. The reason for the lower resource consumption lies primarily in the low input strategy of OF, with the use of no or only small quantities of mineral fertilisers. Recycling farmyard manure on the farm and also using it on arable crops preserves limited resources. Furthermore, organic fertilisers have a very positive impact on soil quality. The major reason for the more favourable results under the headings of toxicity and biodiversity is the low use of pesticides: only a few substances are allowed in organic systems and the total quantities of plant treatment products are substantially lower than in conventional or integrated farming. Nutrient losses in OF were clearly lower per hectare but not always per kg of particular products. In OF farmyard manure is applied mainly to arable crops, whereas non-organic farmers in Switzerland apply slurry and liquid manure mainly to meadows.

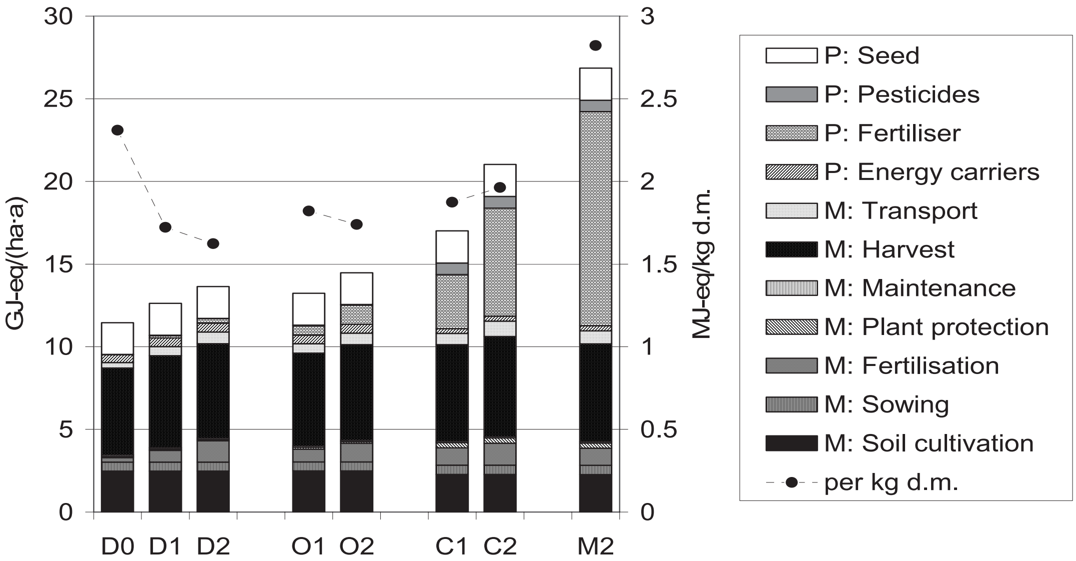


Fig. 1. Demand for non-renewable energy resources (fossil and nuclear) in the DOC experiment over two crop rotation periods (1985–1998). The columns show the energy demand in GJ-equivalents per ha and year (left hand axis); the bullets represent the results in MJ right hand axis). M: machinery inputs, P: means of production. See text for an explanation of the treatment codes.

Nutrient losses in the form of ammonia, nitrate or phosphorus from farmyard manure tend to be higher than from mineral fertilisers (Gaillard & Nemecek, 2006). Additionally organic farmers spread farmyard manure with more applications in smaller quantities at different application times, which tends to increase ammonia losses (Menzi *et al*., 1997). No systematic differences for soil quality compared with IP were found where the same amount of organic fertiliser was applied. Spreading organic fertilisers had a clearly positive effect on a range of soil quality indicators such as organic matter content, aggregate stability, microbial biomass and activity, as well as earthworm biomass. The positive assessment of OF systems in this study cannot be extended to all organic products. Where products like wheat, potatoes or rapeseed from conventional, integrated and organic production are compared on a per kg of product basis, the organic product is not always more environmentally favourable. Higher environmental impacts in OF were often found for global warming potential, ozone formation, eutrophication and acidification compared to IP. Lower yields of certain organic arable crops and frequent use of farmyard manure in organic crops led to a less favourable assessment of the respective products.

The environmental differences between OF and IP were greater for arable crops than for forage production systems. This is because in Swiss integrated forage production, pesticides are used only in very small quantities and fertilisation relies basically on farmyard manure. Therefore integrated and organic forage production systems are rather similar.

The principal needs for improvement in OF lie mainly in increasing yields – especially for potatoes and cereals – as well as minimising nitrogen losses. Optimisation of eco-efficiency in OF should be mainly output-oriented. This means that inputs of limited availability (in terms of quantity and choice) should be used in a way that enables high yields of good quality. However, in integrated production, the use of inputs (fertiliser, herbicide, pesticide) should be optimised in order to minimise environmental impacts per unit of product.

Table 1. *Biodiversity potential (expressed in biodiversity scores) of the eight farming systems in the DOC experiment. See text for an explanation of the treatment codes*

| Biodiversity points | D0 | D1 | D2 | O1 | O2 | C1 | C2 | M2 |
|---|---|---|---|---|---|---|---|---|
| Total species richness | | | | | | | | |
| Total aggregated | 8.7 | 8.1 | 8.0 | 8.0 | 8.0 | 7.7 | 7.6 | 7.6 |
| | | | | | | | | |
| Flora arable land | 14.8 | 13.9 | 13.9 | 13.8 | 13.8 | 12.8 | 12.6 | 12.5 |
| Flora grassland | 4.9 | 4.3 | 4.1 | 4.2 | 4.2 | 4.1 | 3.9 | 3.9 |
| Birds | 10.3 | 8.7 | 8.6 | 8.5 | 8.5 | 8.0 | 8.0 | 7.9 |
| Small mammals | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| Amphibians | 2.5 | 2.1 | 2.1 | 2.1 | 2.1 | 2.0 | 2.0 | 2.0 |
| Molluscs | 2.5 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| Spiders | 13.9 | 13.2 | 13.2 | 13.0 | 13.0 | 12.2 | 12.0 | 12.1 |
| Carabids | 14.7 | 14.0 | 14.0 | 14.0 | 14.0 | 13.7 | 13.5 | 13.6 |
| Butterflies | 9.8 | 8.8 | 8.6 | 8.8 | 8.6 | 8.5 | 8.4 | 8.5 |
| Wild bees | 4.9 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.9 |
| Grasshoppers | 11.0 | 9.8 | 9.5 | 9.9 | 9.6 | 9.4 | 9.3 | 9.3 |
| | | | | | | | | |
| Species with high ecological requirements | | | | | | | | |
| Amphibians | 1.7 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.2 | 1.3 |
| Spiders | 13.4 | 12.7 | 12.6 | 12.5 | 12.4 | 11.6 | 11.5 | 11.6 |
| Carabids | 14.7 | 14.0 | 14.0 | 14.0 | 14.0 | 13.7 | 13.6 | 13.7 |
| Butterflies | 9.8 | 8.8 | 8.5 | 8.8 | 8.5 | 8.4 | 8.4 | 8.5 |
| Grasshoppers | 10.9 | 9.6 | 9.3 | 9.6 | 9.4 | 9.2 | 9.1 | 9.2 |

On the whole, organic arable crop and forage production offers potential for reducing several detrimental impacts on the environment, particularly resource use and emissions of toxic substances, and also has the potential to increase biodiversity. This life cycle assessment study also provides recommendations for the reductions in the environmental impacts of OF systems in Switzerland.

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