Effect of crop management practices on the sustainability and environmental impact of organic and low input food production systems

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Abstract

While organic farming can reduce many of the environmental problems caused by agriculture, organic farming also includes some practices which are questionable in terms of environmental effects. Organic farming practices (rotations, fertilisation regimes, cover crop use) can differ significantly and this leads to large differences in its environmental effects. This leaves considerable scope to improve the environmental effects of organic farming. The environmental aspects of organic farming are discussed, and model simulations are used to illustrate how even moderate changes in organic rotations can have large effects on sustainability, here measured by a simple index of nitrogen lost by leaching relative to nitrogen harvested by the crops. In WP3.3.4 we are working to improve model simulation of organic rotations, and in WP7.1 we are making environmental assessment of organic cropping practices tested in the QLIF project, using model simulations and other approaches.

Introduction

Organic crop production methods are defined by the absence of chemical fertilizers and artificial pesticides. The easy access to fertilizers and pesticides has lead to many of the environmental problems faced by conventional farming today. This is due to direct environmental effects of using fertilizers and pesticides, but also due to indirect effects, not least through the dramatic changes in agricultural practices and specialization they have allowed.

Organic agriculture will of cause remove the direct negative effects of the use of chemicals; no pesticides will pollute the ground water if none are used. However, the more indirect effects of changing to organic practices are more uncertain, and depend on how organic agriculture is practiced. To make sure that organic farming will be of maximum benefit to the environment, it is not enough to comply with current organic farming standards, but essential to optimize the agronomic practicies (e.g. rotation design; type, levels and timing of permitted input used) in organic farming systems.

In this presentation, the main focus will be on the management of nitrogen, as a critical nutrient for the crop production as well as for environmental impact. But there are many other aspects to this subject, e.g. in terms of the pesticides actually accepted in organic farming, of energy use, and of total land use for food production.

Among pesticides, the use of copper and sulphur compounds against insect pests or fungal diseases are obvious examples. Both are broad range pesticides, killing off many other organisms in addition to the target organisms. Copper can accumulate in the soil, leading to a risk of permanent reductions of soil fertility. Thus, organic

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production methods, which can reduce or remove the need for copper or sulphur, will be more sustainable than systems organic where these compounds are used.

Another main topic has been the fact that yield levels are lower in organic farming than in conventional farming. This means that more land must be used for agriculture to supply food for the world population if the crops are grown organically. There are many aspects to this discussion, and it is not as clear cut as just indicated. However, it seems clear that organic systems should be adopted which at least on the longer term produce reasonable yields. Long term green manure is an example of a measure used in organic rotations, which may improve yields of subsequent crops, but at the same time they take up land, and can therefore reduce overall production from the farm.

Without inorganic nitrogen fertilizers, the total nitrogen supply and the nitrogen surplus (kg N ha^{-1}) are typically lower in organic than in conventional farming. Therefore, at least when calculated on an area basis, nitrogen losses to the environment will generally be lower than in conventional farming.

However, in organic farming legumes are grown extensively to add nitrogen to the system. In this way substantial amounts of nitrogen are added, and this can lead to serious losses of nitrogen, if not managed correctly. The use of organic manures adds to long term nitrogen mineralization, and some nitrogen will be mineralized at times when it cannot be used by crops. The manures and green manures are of variable quality and their effect is difficult to predict, making optimization of nitrogen supply difficult (Knappe et al., 2002). Green manures must be grown where the rotations allow this, rather than when it would most optimal due to crop nitrogen demand.

Nitrogen is a more dynamic nutrient in the soil than P or K. Nitrogen in the soil is affected by processes of mineralization, immobilization, denitrification, volatilization, crop uptake and by leaching. Thus, when nitrogen management is not successful, available nitrogen can be lost from the soil in a short time. But this also means that farming practice can strongly influence how much of the soil nitrogen is lost, and how much is used by crops (Torstensson & Aronsson, 2000).

When farmers try to manage nitrogen better, it is mainly the inorganic nitrogen in the soil they should try to manage. This is the nitrogen taken up by the plants, but also the nitrogen which is important in most loss processes. The attempt should be to have available nitrogen in the soil only when crops need it (synchronization), and that the nitrogen is present where the crop can reach it with its root system (synlocation).

A lot of work has been made on the synchronization aspect, studying how the nitrogen mineralization in the soil can be affected, so that nitrogen is released when the crops need it. Another aspect of synchronization is to immobilize nitrogen into organic compounds when it is not needed by main crops, as it can be done by growing autumn catch crops (Thorup-Kristensen et al., 2003).

Much less work has been done on the synlocation aspects, but this is equally important, and especially so when growing catch crops. When catch crops are grown, they change the distribution of nitrogen in the soil profile by leaving available nitrogen in the topsoil and less in the deeper soil layers. It will therefore be an advantage to grow catch crops before shallow rooted main crops. Using deep rooted main crops and catch crops strategically in a crop rotation, and using catch crops before shallow rooted main crops, to “lift nitrogen” to the topsoil layers where they can reach it, are powerful tools in optimizing nitrogen use efficiency in a crop rotation (Thorup-Kristensen et al., 2003).

Materials and methods

The simulations presented are made with a model just developed in the European EU-rotate project. The model has been made with a focus on simulating rotation effects in rotations with a wide range of crops including vegetable crops. The conditions used for the simulations are a typical Danish weather situation, and a Danish sandy loam soil. The rotations are described in Table 1 and 2. There are two groups of rotation comparisons. In the first group of rotations (Table 1), alternative rotation options are tested, to improve the amount of N used for crop production, and reduce the amount of N lost by leaching. In the second group of rotations (Table 2) different catch crop options added to rotation 2 are tested with the same objectives. As a simple index of sustainability used to compare the rotations the ratio of nitrogen lost by leaching to nitrogen harvested with the crops are calculated for each rotation.

In general, the model seems to have overestimated nitrogen fixation in the clover grass ley somewhat. Therefore, harvested nitrogen and nitrogen lost by leaching are presumably too high as well. However, the pattern of loss and response to different management practices seem meaningful, and can be used to understand the typical effects of changes in rotation or catch crop use.

Results

In rotation 1, the nitrogen losses are high, and for each kg of N harvested from the fields, 1.45 kg N is lost by leaching (Table 1). The losses were especially high after year 2 when green manure was ploughed under to establish winter wheat (Figure 1). An obvious solution could be to allow the green manure to grow until winter, and then grow spring wheat instead (rotation 2); we have experimental data showing good results with this. However, the simulations indicate that this only improves the system slightly. So much N is released after green manure incorporation that the spring wheat cannot use it. The nitrogen is left in the soil available for leaching after year 3 instead.

Tab. 1: Four different rotation options simulated with the EU-rotate model. Using rotation 1 as a "standard rotation", changes where made in the other rotations trying to improve their sustainability in terms of N efficiency. Simulated values of harvested N, N lost by leaching and the ratio between the two are shown.

	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Year 1	Barley with undersown clovergrass	Barley with undersown clovergrass	Barley with undersown clovergrass	-
Year 2	Green manure, winter wheat from September	Green manure	Green manure	Barley with undersown clovergrass
Year 3	Winter wheat	Spring wheat	White cabbage	Spring wheat
Year 4	Early potatoes	Early potatoes	Early potatoes	Early potatoes
Year 5	Carrots	Carrots	Carrots	Carrots
Harvested N (kg N/ha/year)	74	72	101	87
Leached N (kg N/ha/year)	107	101	73	69
Lost N to harvested N ratio	1.45	1.40	0.72	0.79

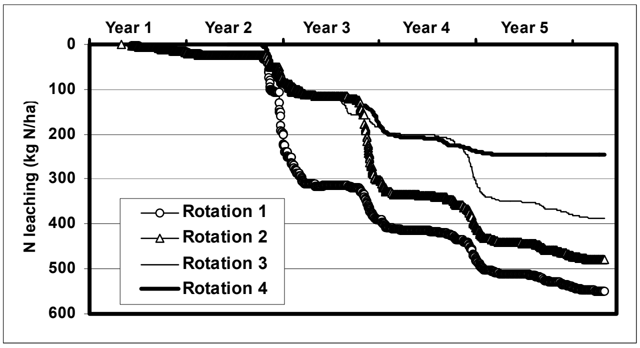

Figure 1: Nitrogen leaching during five-year rotations (see Table 1). In rotation 2, the winter wheat from rotation 1 is replaced by spring wheat to avoid early plough down of green manure, in rotation 3, spring wheat is replaced by cabbage to increase crop N removal, and in rotation 4 the green manure period is reduced by one year to reduce total N input.

Adding a more N demanding crop as cabbage instead of spring wheat (rotation 3) reduces losses more, and only 0.72 kg N is then lost per kg N harvested. The main leaching now occurs one year later after year 4, as the N rich residues of cabbage adds more to the leaching loss in year 4 than the N poor wheat residues. Another option is to reduce N input to improve the N balance. In this case, the green manure period was reduced with one year (rotation 4). This reduces the N surplus and the leaching loss very much, and shortens the rotation with one year. Thereby, the ratio of N lost to N harvested is improved to 0.79, almost as in rotation 3.

Tab. 2: Different use of catch crop in the rotation simulated with the EU-rotate model. Based on rotation 2 (Table 1), simulations were made to test the possibilities for optimizing rotation sustainability in terms of N efficiency by growing catch crops. Simulated values of harvested N, N lost by leaching and the ratio between the two are shown.

	Rotation 2	Rotation 5	Rotation 6	Rotation 7	Rotation 8
Year 1	Barley with undersown clovergrass	Barley with undersown clovergrass	Barley with undersown clovergrass	Barley with undersown clovergrass	Barley with undersown clovergrass
Year 2	Green manure	Green manure	Green manure	Green manure	Green manure
Year 3	Spring wheat	S. wheat + f. radish catch crop	S. wheat + ryegrass catch crop	S. wheat + f. radish catch crop	S. wheat + f. radish catch crop
Year 4	Early potatoes	Early potatoes	Early potatoes	Early potat. + rye catch crop	Late potatoes
Year 5	Carrots	Carrots	Carrots	Carrots	Carrots
Harvested N (kg N/ha/year)	72	83	79	91	93
Leached N (kg N/ha/year)	101	76	81	58	64
Lost N to harvested N ratio	1.40	0.92	1.02	0.63	0.69

As it may be difficult to synchronize the N release from green manure or organic fertilizers with the demand of the cash crops, the system may be improved by adding autumn catch crops. They can retain N in the system during winter and release it for later crops. In the spring wheat system (rotation 2), adding a catch crop after wheat (rotation 5, Table 2), strongly reduced leaching. Again, some of the leaching came later, in the autumn of year 4 rather than in year 3 (Figure 2), but overall losses were reduced and total N harvested with the crops were increased with 10-15%. All together, the ratio of N lost to N harvested was reduced to 1.02 when a ryegrass catch crop was grown and to 0.92 when a deep rooted fodder radish catch crop was grown.

In a next step, it was attempted to reduce the N losses in year 4 after potatoes. In one attempt the N demand was increased by switching from early to late potatoes (rotation 8), alternatively, an extra catch crop was added after potato harvest (rotation 7). Both options reduced N lost to N harvested ratio effectively to only 0.69 or 0.63.

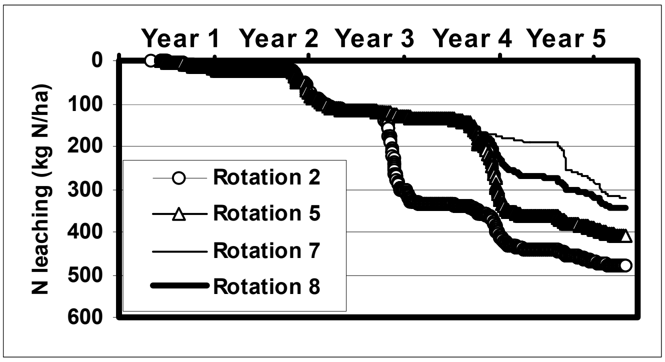

Figure 2: Nitrogen leaching using different catch crop options (see Table 2). In rotation 5 a fodder radish catch crop is grown after spring wheat, in rotation 7 a catch crop is also grown after potaoes in year 4. In rotation 8 early potatoes are replaced by late potatoes to increase crop N demand and use more of the N effect of the catch crop in year 3.

Discussion

Together, these simulations indicate several possibilities for improving system performance, by matching N supply and N demand better, in amount, timing and placement. Changing the time of N release, as when the green manure is incorporated during winter rather than during early autumn to establish winter wheat, can have big effects too (Francis, 1995). But a major improvement is only seen if there is a demand for the N at the later time when it is now released. That is why it was much better when white cabbage rather than spring wheat was grown after the green manure.

The results show that using catch crops to make a more optimal timing of N availability in a rotation can be a strong tool to improve N use efficiency in organic crop rotations. In the present examples, delaying the N release during the early stages of the rotation after green manure had limited effect unless very N demanding crops were grown, as at this stage N availability was in general high compared to crop N demand. At the later stages, as exemplified by the second catch crop grown after potatoes, a delay in

N availability may have a very good effect on total N use efficiency, as at this stage of the rotation the main crops are generally N limited, and can use the N when it is released at a later time.

The need to synchronize N availability exactly to crop N demand depends also on crop rooting depth. In these simulations this has only been indicated by the comparison of the deep rooted fodder radish catch crop to the more shallow rooted ryegrass. However, experimental results have shown that when growing deep rooted crops, N that was “lost” some time earlier may still to a great extent be used by the crops, but when growing shallow rooted crops it is important than N is only released in the soil shortly before the crop needs to use it (Thorup-Kristensen, 2006). Therefore, shallow rooted crops should only be grown in the parts of the rotation where optimal timing of N availability can be made, whereas, when this is not possible, deep rooted crops or catch crops should be grown to recover nitrogen leached to deeper soil layers.

Conclusions

Model simulated effects of different rotations and management options do not present real data, and they should be interpreted with care. However, using simulation models, much more options can be tested than in field experiments. When used in combination with real field trials, model simulations can be a very strong tool to extend the results and conclusions we can draw from the experiments, and analyze how rotations can be improved (Schoop, 1998). Models can also analyze aspects of the field experiments which are not always measured, e.g. nitrogen leaching loss. Using simulation models therefore seem a strong approach to evaluate N effects in organic farming, both effects on yield and on leaching loss to the environment.

Model simulations will be employed in WP7.1 of the QLIF project to analyze environmental effects of the cropping practices tested in some of the QLIF field experiments. Other approaches will be employed to test other aspects of system sustainability.

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