Chapter 7

Use Efficiency and Leaching of Nutrients in Organic and Conventional Cropping Systems in Sweden

Lars Bergström, Holger Kirchmann, Helena Aronsson, Gunnar Torstensson, and Lennart Mattsson

Department of Soil and Environment, Swedish University of Agricultural Sciences, P.O. Box 7014, SE-75007 Uppsala, Sweden

E-mail of corresponding author: lars.bergstrom@mark.slu.se

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Abstract In the past few years, organic farming has been proposed as a possible way of reducing N leaching from agricultural soils and improving the use efficiency of plant nutrients. This is, to a large extent, considered to be attributed to the fact that synthetic fertilisers are not allowed in such systems and the N inputs mainly originate in various types of organic manures. In this overview, results from a number of Swedish field studies are presented in which crop yields, nutrient-use efficiencies and leaching in organic and conventional systems are evaluated. Some studies were conducted in lysimeters and others in large tile-drained field plots. In two lysimeter experiments, leaching of N derived from either poultry manure or red clover (*Trifolium pratense* L.) green manure were compared with fertiliser N, all labeled with 15-N. In the lysimeters on which poultry manure was applied, 32% of N applied leached during three years, whereas only about 3% leached in ammonium nitrate fertilised lysimeters. In plots on a sandy soil, annual N leaching loads averaged over the whole 6-yr crop rotation reached 39 kg N ha^{-1} in the organic rotations and 25 kg N ha^{-1} in the conventional rotation. Phosphorus-leaching loads were overall small in all systems, whereas K leaching was highest in the conventional rotation (i.e., on average, 27 kg ha^{-1} yr^{-1}). In terms of crop yields, they were reduced by 20 to 80% in the organic rotations compared to the same crops in the conventional rotations. This was explained in terms of N deficiency, weed competition, and infestation of crop diseases in the organic systems. These results suggest that organic crop production uses agricultural soils less efficiently, with no benefit for water quality.

Keywords Crop yields · Fertilisers · Manures · Water quality · Weed pressure

1. INTRODUCTION

All forms of agriculture have the ultimate goal of producing abundant and nutritious food at a reasonable cost, with a minimum of disturbance to the environment and in a sustainable manner. In conventional agriculture, this has been achieved by a number of different technologies that have continuously been refined over time. Despite such technological improvements, agricultural activities can cause environmental disturbances, of which contamination of various water bodies by nutrients is among the most serious. During the past couple of decades, eutrophication has been the driving force for development of efficient countermeasures to reduce N leaching losses from agricultural fields. These include cover crops (Aronsson, 2000), use of controlled-release fertilisers (Giller et al., 2004) and conservation tillage practices to reduce P losses (Withers and Jarvis, 1998). In parallel, whole farming concepts (organic, integrated) have been proposed as a solution for more environmentally sensitive production. Organic farming has received a lot of attention among the scientific community, farmers and the general public since it has been suggested that this type of agriculture is the way forward. Today organic farming is practised in many countries around the world and intensive lobbying has also triggered some political actions. For example, a few years ago, the Swedish government set up the goal that by the year 2005, 20% of agricultural soils should be under organic farming. However, this goal was not reached and only approximately 13% of Swedish arable land is currently (2008) cultivated according to organic practices. It is important to note that there is a lack of scientific evidence to support such political actions (Trewavas, 2004). Nevertheless, organic farming is the only farming system to be legally defined in various regulations, due to the fact that it is believed to be superior in terms of sustainability (Watson et al., 2002).

The other farming concept that strives to achieve long-term sustainability is integrated farm management. The fundamental concept behind integrated farming is to combine the best of traditional farming with sensible use of modern technology (Trewavas, 2001). What really distinguishes organic from integrated and conventional cropping systems is the *a priori* exclusion of soluble inorganic fertilisers and synthetic pesticides in the former. Only nutrient inputs in various organic forms (e.g. animal and green manures) or untreated, naturally occurring minerals, often with very low solubility (e.g. apatite for P), can be used in organic farming.

Key components of soil fertility and nutrient-use efficiency in organic cropping systems have been examined in several studies (see Supplement to Soil Use and Management vol. 18, 2002). However, there is a tendency to consider the entire systems rather than studying single processes in the different systems. This is due to a resistance among researchers who have a positive attitude towards organic farming to make direct comparisons between certain aspects or isolated processes of two systems (e.g. organic and conventional systems; MacKerron et al., 1999) but to be biased towards a holistic approach (Fjelsted Alrøe and Kristensen, 2002). This is certainly true for comparisons of both nutrient leaching (see review by Kirchmann and Bergström, 2001) and crop yield (e.g. Ivarson and Gunnarsson, 2001) in organic and conventional systems. Any estimates made are often based on nutrient budgets (e.g. Halberg et al., 1995; Dalgaard et al., 1998; Hansen et al., 2001), mineral N content in soil (Watson et al., 1993; Kristensen et al., 1994) or modelling (Johnsson et al., 2006) rather than direct measurements. In terms of leaching, the nutrient surpluses calculated in this way are simply indicators of the potential losses from the systems (Dalgaard et al., 1998) with no partition between different losses (e.g. leaching, denitrification or volatilisation in the case of N). It is also quite common to base leaching estimates on nutrient concentrations obtained from soil water samples in porous suction probes and water flux calculations with mathematical simulation models (e.g. Stopes et al., 2002), which also generates uncertain load estimates. Another limitation of a number of leaching studies is that leaching loads are only related to the cropping area, disregarding yield differences (Corré et al., 2003; Kirchmann and Bergström, 2001), which can lead to erroneous conclusions about the environmental benefits of organic systems (e.g. Stockdale et al., 2001). The leaching measurements presented in the present overview were carried out in tile-drained field plots or field lysimeters.

In this overview the following questions are discussed: (i) How are yield levels and plant nutrient uptake affected in organic and conventional systems? (ii) Do leaching losses of nutrients decrease following a change to organic cropping practices in which organic manures are used rather than soluble mineral fertilisers? (iii) Are there significant differences in nutrient-use efficiency between organic and conventional cropping systems? (iv) How does weed pressure in an organic system affect the N balance? The presentation is based on published Swedish field studies carried out in plot experiments (Torstensson et al., 2006; Kirchmann et al., 2007) and lysimeters (Bergström and Kirchmann, 1999; 2004) during periods ranging from 2 to 18 years.

2. BRIEF DESCRIPTION OF SITES

2.1. Lysimeter studies in Uppsala

The lysimeters included in this overview contained an undisturbed sandy soil profile (0.3-m diam. and 1.0-m long) collected at the Mellby site described below. The soil columns were collected with a coring technique which ensures that the integrity of the soil is maintained (Persson and Bergström, 1991), and side-wall flow effects are minimized (Bergström et al., 1994). After collection, the soil profiles were placed in a lysimeter station in Uppsala, Sweden (Bergström, 1992), where they were kept for the duration of the experiments.

Two experiments are reported and discussed here; one in which plant uptake and leaching of mineral N fertiliser (NH_4NO_3) were compared with N derived from anaerobically-stored poultry manure, and the other in which comparisons were made with red clover (*Trifolium pratense* L.) green manure. All N sources were ^{15}N-labelled to allow quantification of N deriving from the respective source, and applied at rates of 80-160 kg N ha^{-1} during the initial year. Plant uptake and leaching of added N were then monitored during 2-3 years.

The experiments are described in detail by Bergström and Kirchmann (1999; 2004).

2.2. Field study at Mellby

The Mellby site, where the tile-drained field plots included in this overview are installed, is located in southern Sweden (56^{o}29’N, 13^{o}0’E). The soil at the site is a sandy loam with sand content between 77 and 91% down to 1.0-m depth. The organic matter content is relatively high in the topsoil (4%), but very low further down in the profile. Drainage flows from the plots were recorded continuously and water samples for chemical analysis were collected biweekly. Crop samples were also collected at harvest each year.

Two 6-yr organic crop rotations and one conventional rotation are included in this overview. In one of the organic rotations, animal manure was used (OAM), whereas N was provided from green manures (a legume/grass mixture) in the other (OGM). In the conventional rotation (CON), perennial ryegrass (*Lolium perenne* L.) or winter rye (*Secale cereale* L.) were used as cover crops in an attempt to reduce N leaching. All crop rotations had predominantly spring cereals, except during the final year when potatoes were grown (Table 1). The OGM rotation had green manures during two of the six years and the OAM rotation had forage crops during two years (Table 1). The crops in the conventional rotation received on average 97 kg N ha^{-1}, 24 kg P ha^{-1}, and 85 kg K ha^{-1} as inorganic fertilisers. The corresponding inputs in the organic rotations were: 71 (total-N), 0 (total-P) and 25 (K) kg ha^{-1} in the OGM rotation, and 121 (total-N), 6 (total-P) and 60 (K) kg ha^{-1} in the OAM rotation.

A more detailed description of the site and experimental procedures can be found in Torstensson et al. (2006).

2.3. Field study at Bjärröd

Table 1. Crop rotations and mean nutrient input at the Mellby and Bjärröd sites (data from Torstensson et al., 2006; Kirchmann et al., 2007)

	Cropping systems at Mellby			Cropping systems at Bjärröd	
	Organic with animal manure	Organic with green manure	Conventional	Organic	Conventional
Crop rotations					
Year 1	Barley	Oats	Barley	Barley	Barley
Year 2	Clover/grass ley	Green manure	Oats	Red clover	Clover/grass ley
Year 3	Clover/grass ley	Spring wheat	Spring wheat	Winter wheat	Oilseed rape
Year 4	Oats	Oats	Barley	Beans	Winter wheat
Year 5	Pea/barley	Green manure	Oats	Potato	Oats
Year 6	Potato	Potato	Potato	Peas	Sugarbeet
Mean nutrient input (kg ha^{-1} yr^{-1})					
N[a]	121	71	97	108	147
P	6	0	24	50	29
K	60	25	85	43	82

[a]Nitrogen input data include N_2-fixation. Figures were estimated using above-ground crop data as an input to the STANK model (Version 4:1, Swedish Board of Agriculture), which includes a grassland submodel according to Fagerberg et al. (1990).

The long-term experiment at Bjärröd in southern Sweden (55°42'N, 13°43'E) was carried out on a sandy loam soil (13-14% clay, 23-24% silt and 62-64% sand, throughout the profile to 1.0-m depth). Before the start of the experiment in 1980, the soil was highly P and K depleted, due to the fact that no inorganic fertilisers (or pesticides) had been applied since the mid-1940s.

In this presentation, data from two cropping systems are discussed, one organic and one conventional, both designed to support dairy production but with different crop rotations. Unfertilised plots with a similar crop rotation to the conventional system were used as a reference system. The cropping systems were laid out in tile-drained plots with a net size of 35 x 90 m each. The major management differences between the organic and conventional systems were: (i) growth of legumes every second year in the organic rotation and use of legumes as cover crops; (ii) application of P in the organic system at higher rates than inorganic P fertiliser in the conventional system; (iii) exclusion of oil-seed rape (*Brassica napus* L.) and sugarbeet (*Beta vulgaris* L.) in the organic system, but inclusion of potato (*Solanum tuberosum* L.); (iv) frequent mechanical weeding in the organic system, whereas pesticides were used in the conventional system; and (v) use of solid animal manure in the organic system and slurry in the conventional system. The mean annual inputs of N, P and K were: 147, 29 and 82 kg ha^{-1}, respectively, in the conventional system, and 108, 50 and 43 kg ha^{-1} in the organic system. The 6-yr crop rotations (Table 1) were repeated 3 times, giving a total experimental period of 18 years. Crop samples were collected at harvest each year.

More information about the site, crop rotations and other experimental procedures is provided by Kirchmann et al. (2007).

3. YIELD LEVELS AND NUTRIENT UPTAKE BY CROPS

An important consideration when comparing crop yields and nutrient removal by crops in organic and conventional systems is how the systems are managed. Organic and conventional systems differ in a number of aspects apart from use of fertilisers and pesticides. For example, green manure crops are grown in organic systems on a regular basis to provide succeeding crops with N, whereas this is uncommon in conventional systems. Furthermore, the crop rotations included in the studies reviewed here were quite different, which made comparison of crop yields between the conventional and organic systems difficult.

At the Mellby site, barley (*Hordeum distichum* L.) yield in the OAM system was only 50% of that in the conventional plots, while yield of spring wheat (*Triticum aestivum* L.) in the OGM system was about 80% of that in the conventional system. The average annual yield of all grain crops was significantly ($P < 0.1$) higher in the conventional system than in the organic system with green manures (OGM), as was the amount of N harvested with the crop ($P < 0.05$). This indicates that the N release from the green manure, which was incorporated into soil in late autumn, was not adequate for crop requirements. The most remarkable difference in crop yields and N harvested with crops occurred when potatoes were grown. In the conventional system, the potato yield was 9118 kg DM ha^{-1}, whereas it was only about 1500 kg DM ha^{-1} in the organic systems. The main reason for this large difference was damage by potato blight fungus (*Phytophthora infestans*) in the organic systems, whereas this problem was eliminated by use of fungicides in the conventional system. An additional contributing factor for the low potato yields in the organic systems was most likely K deficiency. The amount of K in harvested potatoes was only about 30 kg K ha^{-1} in the organic systems, whereas it was 175 kg K ha^{-1} in the conventional system.

At Bjärröd, the mean yield level of the organic system, including all crops, amounted to only 50% of the conventional yield (i.e. 3170 vs. 6380 kg DM ha^{-1} yr^{-1}, Table 2). For the individual crops, yield of sugarbeet in the conventional rotation was the main reason for the large difference between the systems, illustrating the basic problem when comparing cropping systems with different cropping sequences, as mentioned above. When sugarbeet yield was excluded from the comparison, the conventional system produced on average 5140 kg DM ha^{-1} yr^{-1} and the organic system 62% of that amount. This figure is similar to official Swedish statistics (SCB, 2004), which report mean organic yields amounting to 50-70% of those in conventional cropping systems. As regards the other crops, mean yields of grass ley were not significantly different between the organic and conventional cropping systems, but yields of cereal crops were significantly lower ($P < 0.01$) in the organic rotations (Table 2). There are several possible reasons for the lower yields in the organic system, e.g. lower inputs of N, greater weed competition, lower nutrient-use efficiencies and poorer control of pests and diseases.

The concentrations of N, P and K in grains of barley and winter wheat at Bjärröd were significantly different ($P < 0.05$) between the conventional and organic systems. Nitrogen concentrations were lower in the organically grown cereals (1.8-2.2%) than in the conventional (2.2-2.7%), whereas P and K concentrations were slightly higher in the organic system (0.41% P and 0.51% K vs. 0.38% P and 0.44% K). Higher N concentrations in the conventional cereals and higher concentrations of P in the organic cereals were expected, since the application rates of N were higher in the conventional system and those of P in the organic. However, the organic system received considerably less K (43 vs. 82 kg K ha^{-1} yr^{-1}), but the concentrations of K were still higher in organic cereals. A contributing factor to this could be the much lower cereal yields in the organic system (Table 2).

A reduction in crop yields in organic systems, which has been reported in a number of other long-term experiments besides those referred to here (e.g. Aronsson et al., 2007; Leake,

Table 2. Average dry matter yields at the Mellby (1997-2002) and Bjärröd (1981-1998) sites. Standard errors (± SE) for the Bjärröd site and relative yield figures are given in brackets (data from Torstensson et al., 2006; Kirchmann et al., 2007)

Site and cropping system	Dry matter yield (kg ha^{-1})			
	All crops	Barley	Winter wheat	Cover/grass[a]
Mellby				
Conventional	6096 (100)	4480 (100)	Not grown	Not grown
Organic with green manure	1951 (32)	Not grown	Not grown	Not grown
Organic with animal manure	5682 (93)	2133 (48)	Not grown	9442
Bjärröd				
Conventional	6380 (±755)a[b] (100)	3745 (±650)a (100)	6075 (±524)a (100)	7480 (±755)a (100)
Organic	3170 (±436)b (50)	2105 (±176)b (56)	4200 (±544)b (69)	6140 (±146)a (82)
Unfertilised	2080 (±336)c	1119 (±75)c (30)	3680 (±644)c (60)	Not grown

[a]Clover/grass includes weeds.
[b]Within columns, mean values followed by different letters are significantly different at $P < 0.05$.

1999; 2000), has to be taken seriously, considering that future population growth will require more food to be produced. In this context, it is critical to increase or at least maintain yields per area without jeopardising environmental quality. Therefore, one can question whether organic crop production is a viable alternative, since large yield reductions for organically grown crops have to be compensated for by an increase in agricultural land. Results obtained in the experiments included in this overview show that crop yields in organic rotations were reduced by 20 to 80% compared with the same crops in conventional rotations. These examples indicate that organic crop production uses agricultural soils less efficiently, which is further discussed below and also in Chapter 3 of this book (Kirchmann et al., 2008).

4. ARE THERE ANY WATER QUALITY BENEFITS ASSOCIATED WITH ORGANIC AGRICULTURE?

One of the main arguments for changing over to organic crop production is that it is beneficial for the environment, especially water quality. A large proportion of the general public believes that nutrient loads to surface waters and groundwater decrease in response to management and use of nutrients according to organic principles (Granstedt, 1995). Conventional farms tend to operate at greater input levels of most nutrients than organic systems, as revealed by a

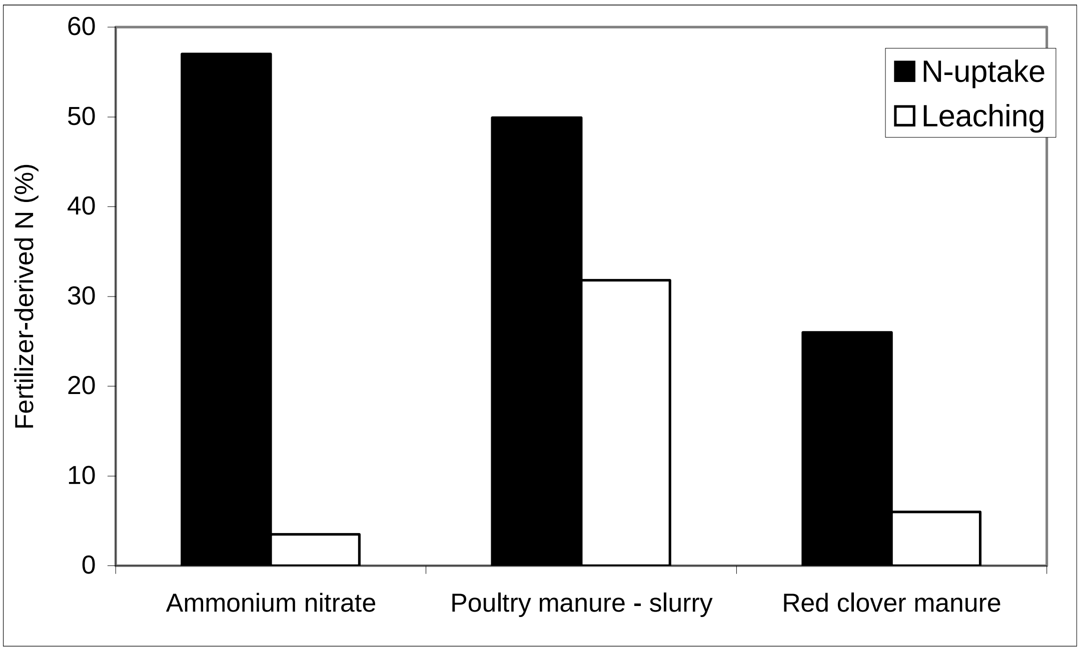

Figure 1. Leaching and crop uptake of N originating from mineral fertiliser, poultry manure and red clover manure, measured in field lysimeters (modified from Bergström and Kirchmann, 1999; 2004).

compilation of farm-gate balances (Kirchmann and Bergström, 2001). Many expect this to result in larger leaching losses, primarily of N. However, is this really the case?

The main difference between organic and conventional agriculture regarding the use of plant nutrients is the exclusion of soluble inorganic fertilisers in the former. Therefore, in a first step we need to investigate the difference in leaching behaviour between organic manures and inorganic fertilisers. This was done with respect to N in two lysimeter studies in which NH_4NO_3 was compared with different types of poultry manure (Bergström and Kirchmann, 1999), although, only poultry manure anaerobically stored will be considered here, and green manures (Bergström and Kirchmann, 2004). Over the 3-yr period following application of poultry manure and fertiliser in the first year, leaching of N derived from the respective N sources was 3.5 kg ha^{-1} of added NH_4NO_3 and 31.8 kg ha^{-1} of N in poultry manure (Fig. 1). This represented about 3.5 and 32% respectively of added N, since 100 kg N ha^{-1} of both N sources were used. In the comparison between NH_4NO_3 and red clover manure over 2 years, the corresponding figures were 4 and 6%, respectively (Fig. 1). Thus, leaching of fertiliser N was lower throughout, although the difference in N leaching between the two organic N sources investigated was quite large. This is a clear indication that organic N sources are more vulnerable to leaching than inorganic N fertilisers. Incorporation of animal and green manures carries with it a high risk of N loss by leaching, due to the fact that the inorganic N is often released from these sources during periods when there is no crop uptake of N. In cold and humid regions, such as Sweden, this often coincides with climatic conditions in autumn, when both soil temperatures and moisture content are high enough to trigger mineralisation of organic N fractions and annual crops are harvested. This released inorganic N is highly exposed to leaching, due to the frequently large surplus amount of precipitation. A leaching experiment with pig slurry applied in increasing amounts to lysimeters of the same type as those described above clearly corroborated this (Bergström and Kirchmann, 2006). The slurry was applied during 2 of 3 years at annual rates ranging from 50 to 200 kg N ha^{-1}. For comparison, NH_4NO_3 was applied on other lysimeters at

Table 3. Average annual leaching loads of N, P and K per unit area and per unit harvested dry matter crop yield at the Mellby site (1997-2002) in southern Sweden (data from Torstensson et al., 2006)

Cropping System	N	P	K	N			P			K		
				All crops	Cereals	Potato	All crops	Cereals	Potato	All crops	Cereals	Potato
	Leaching (kg ha^{-1})			Leaching (kg Mg^{-1} dry matter yield)								
Conventional	25	0.2	27	4.1	3.4	5.9	0.03	0.04	0.01	4.43	5.6	2.3
Organic with green manure	34	0.1	16	17.4	7.8	53.3	0.05	0.02	0.08	8.20	5.3	12.4
Organic with animal manure	39	0.2	12	6.9	6.3	62.6	0.03	0.05	0.08	2.12	3.0	6.5

a rate of 100 kg N ha^{-1} yr^{-1}. During the 3-yr period, N leaching loads increased with increasing slurry application rate to an average of 139 kg N ha^{-1} at the highest application rate. When slurry-derived N was applied at or above the application rate of inorganic fertiliser-N, the loads were significantly larger ($P < 0.05$), but crop yields were not increased. This study further confirms that organic N sources are less efficiently used by crops than inorganic N fertilisers under cold humid conditions and increase the risk of leaching. However, it is important to note that comparative fertiliser experiments, such as those discussed above, only provide indications of how leaching would proceed in an agricultural system.

In the Mellby study, in which realistic organic and conventional systems were compared, annual N leaching loads, averaged over the whole 6-yr crop rotation, were 39 kg ha^{-1} (organic with animal manure; OAM), 34 kg ha^{-1} (organic with green manure; OGM), and 25 kg ha^{-1} (conventional with cover crops; CON) (Table 3). However, as it is difficult to compare leaching data due to different crops being included in the rotations, we limited the comparison to years with simultaneous grain crops (3 out of 6 years in the CON and OGM rotations). In this more strict comparison, the annual average N leaching load was significantly ($P < 0.05$) smaller in the CON system than in OGM (13 vs. 22 kg ha^{-1}). As these data were derived from real cropping systems, the results strongly support the hypothesis that organic systems leach more N, which, over the long-term, must have a considerable impact on surface water and groundwater quality. In all systems, the largest leaching loads by far occurred when potatoes were grown, with as much as 98 kg N ha^{-1} leached in the organic system with animal manure (OAM), which represented about 40% of the total load during the 6-yr period. Large N leaching loads with potato crops are quite common (Madramootoo et al., 1992), due to a number of conditions such as: shallow root system, large N fertiliser applications, and intensive tillage operations before planting and after harvest, to mention a few. However, the large N leaching loads from the organic systems at Mellby were primarily due to the extremely low potato yields caused by the blight fungus infestation, as mentioned above. In the Bjärröd experiment, the highest N concentrations in water draining from large lysimeters (34 mg N L^{-1}) also occurred in conjunction with potato crops in the organic system (Kirchmann et al., 2007).

Overall, the annual average leaching loads of P at Mellby were small in all systems, not exceeding 0.2 kg ha^{-1} (Table 3). This is mainly attributable to the strong adsorption ability of layers in the soil profile with a high iron content (Ghorayshi and Bergström, 1991). The annual average leaching loads of K were highest in the conventional rotation (Table 3), and these were significantly higher ($P < 0.05$) than in the OGM rotation as regards grain crops. This was presumably due to the much larger inputs of K in the conventional system, which annually received on average 85 kg K ha^{-1} compared to 25 kg K ha^{-1} in the OGM rotation.

It is obvious from the results presented above that proportionally less N is removed by crops and more N is thereby potentially available for leaching in organic cropping systems than in conventional, despite an often lower input of N in organic systems. This was also shown in a study carried out on a clay soil in southwest Sweden, in which conventional and organic systems were compared (Aronsson et al., 2007). It is also obvious from these studies that N leaching per hectare is not reduced when organic manures are used instead of inorganic N fertilisers.

When comparing N leached in relation to N in harvested crops, we need to consider certain practical factors in the systems studied. In Swedish organic systems, green manure crops are grown during a whole summer season, precluding harvest of other crops. In the Mellby study, green manure crops were grown during 2 out of 6 years in the OGM rotation, which means that the allocated production area was 33%. When N leaching loads per hectare in each system were divided by the corresponding dry matter yields of harvested crops, the lowest leaching (approx. 4.1 kg N Mg^{-1} dry matter yield) occurred in the conventional system, compared to 6.9 and 17.4 kg N Mg^{-1} dry matter yield for the OAM and OGM systems, respectively (Table 3). Comparing N leaching loads in relation to the crop grown, it was obvious that potatoes caused the highest N leaching loads in all systems, especially in the organic systems (62.6 and 53.3 kg N Mg^{-1} dry matter yield for the OAM and OGM systems, respectively; Table 3). Furthermore, leaching loads of P per unit dry matter yield were not reduced in the organic systems.

These results clearly suggest that inorganic N fertilisers are used more efficiently than green and animal manures. Furthermore, even viewed from a cropping systems perspective, nutrient losses are less in conventional farming systems, both per unit area and per unit crop yield. Still, we also have to consider the changes in agricultural land required to produce the same amount of food if arable land is cropped according to organic rather than conventional principles. In other words, the results need to be integrated into a land-use perspective to determine the impact of organic and conventional systems on water quality (Fig. 2).

The Mellby and Bjärröd studies showed that yield levels in organic production are on average about 60% of those in conventional cropping systems. This difference is confirmed by data reported in the official agricultural statistics of Sweden, which is discussed in Chapter 3 of this book (Kirchmann et al., 2008). Therefore, to produce the same amount of food through organic farming, the organically managed area must be increased by 67% to compensate for the 40% yield loss. This would mean that non-arable land such as extensively managed rangeland, woodland, or other semi-natural land would have to be converted to arable land. In general, such land uses cause lower leaching losses than arable land. Accordingly, leaching from a

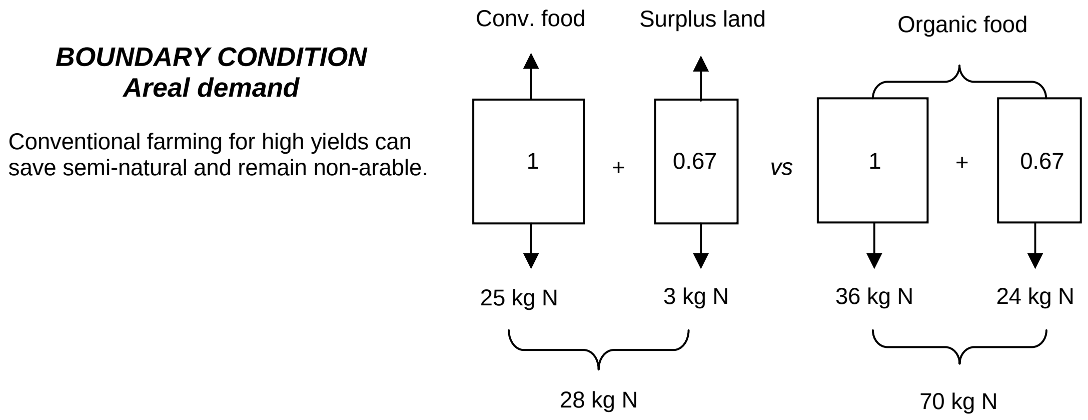

Figure 2. A comparison of farming systems producing similar products but with an organic yield only 60% of that in conventional production. The same area of land required for low-yielding (organic) systems must also be considered for high-yielding (conventional) systems. Yield and leaching figures for arable land are taken from Tables 2 and 3. Leaching data for semi-natural land are taken from Löfgren and Olsson (1990).

larger area of organically managed land needs to be compared with leaching from a smaller conventionally managed area plus a non-arable area required to make the organic and conventional areas of equal size. Such a comparison, which takes into account food supply and land demand based on yield reduction, shows that N leaching will be approximately 2.5 times higher from organic than conventional production (Fig. 2). In summary, the necessary expansion of agricultural land to maintain food production through organic methods will most likely have negative effects on water quality with regard to N.

5. NUTRIENT-USE EFFICIENCY IN ORGANIC ANDF CONVENTIONAL CROPPING SYSTEMS

Short-term measurements of nutrient-use efficiency over a few years can be misleading if the residual effect of previously used nutrient sources is not accounted for. This is critical if organic nutrient sources and untreated minerals, which are frequently used in organic agriculture, are included. In such cases, long-term calculations such as those permitted by the results from the Bjärröd site seem more appropriate. As reported above, crop uptake of nutrients was measured over 18 years in the organic and conventional systems at Bjärröd, to which the examples presented below refer.

The use efficiency of inorganic N and P fertilisers was higher than that of organic sources or untreated minerals (Table 4). In particular, crop utilisation of P was as low as 7% in the organic system compared to 36% in the conventional system. It is reasonable to assume that the large application of sparingly soluble apatite-P (once at 646 kg P ha^{-1}) greatly reduced the P use efficiency. When apatite-P was excluded from the calculation, the P use efficiency increased to 20% in the organic system, which is still considerably less than in the conventional system. The use efficiency of K was 63% in both the organic and conventional systems, most likely due to the fact that K was mainly added in easily soluble form in both systems and not at excessive rates. The long-term agronomic efficiency of N (the increase in grain yield compared to the unfertilised control divided by the N input) was significantly lower in the organic system

Table 4. Long-term use efficiency of N, P and K additions at the Bjärröd site (Kirchmann et al., 2007)

Measure of efficiency	Organic system	Conventional system
Agronomic efficiency of N[a]		
Barley	9 kg yield increase kg^{-1} N	18 kg yield increase kg^{-1} N
Winter wheat	10 kg yield increase kg^{-1} N	16 kg yield increase kg^{-1} N
Use efficiency[b]		
P	7%	36%
K	63%	63%

[a]The long-term agronomic efficiency of N by grain crops (1981-1998) was calculated as the increase in grain yield compared with the control divided by the N input.

[b]The long-term use efficiency of P and K by all crops (1981-1998) was derived from nutrient removal (nutrient yield of treatment – nutrient yield of control) divided by the nutrient input.

than in the conventional (10 and 17 kg cereal yield increase per kg N added, respectively) (Table 4). The lower N use efficiency in the organic system was primarily due to poor synchronicity between mineralisation of N from the organic sources and crop N demand, as discussed above, but was also due to competition for N by weeds (see below).

For the poultry manure and the red clover green manure used in the lysimeter studies, the N use efficiency was 50 and 24%, respectively, over the 3- and 2-yr periods. When NH_4NO_3 was used, the corresponding figure was 57%. Again, lack of synchronicity between mineralisation and crop uptake of N was the main reason for this difference between the N sources.

A key question is whether the shortage of available N when using organic manures is limited to the studies referred to here, or whether it is characteristic of other organic cropping systems as well (see Clark et al., 1999). It is quite obvious that organic cropping systems rely for their N supply on biological N fixation or on purchased organic N sources, since the occurrence of untreated N minerals (Guano, Chilean nitrate) is scarce in the world. Purchased organic N sources (e.g. meat and bone meal, food industry wastes, animal manure) often originate from conventional production, which shows a reliance on conventional production. Irrespective of the organic N source used in organic crop production, several studies have shown that they provide the crop with less N than similar amounts of N applied as mineral fertiliser (e.g. Thomsen et al., 1997; Aronsson et al., 2007; Bergström and Kirchmann, 2006). Thus, a lower N use efficiency seems to be a common problem in organic cropping systems, despite the fact that N inputs tend to be lower in organic systems than in conventional.

6. WEED PRESSURE IN THE LONG-TERM

Another possible reason why yields are typically lower in organic cropping systems is weed competition as discussed in Chapter 3 of this book (Kirchmann et al., 2008). There is reason to believe that competition between weeds and crops is higher in organic systems and also that the weed pressure gradually increases in response to lack of herbicide use. This aspect is not well documented, or at least not the long-term effects.

At the Bjärröd site, weed biomass and removal of N by weeds were measured each year in all systems (unfertilised control, organic and conventional). These measurements showed that weed biomass was a significant component of the organic system, amounting to on average 1021 kg DM ha^{-1} yr^{-1}, with peak values of more than 3000 kg DM ha^{-1} yr^{-1}. These peak values occurred during years with legumes (peas and beans) whereas during years with winter wheat the weed biomass was similar to that in the conventional system. It is also notable that the presence of weeds increased over time in the organic system, by about 17 kg DM ha^{-1} yr^{-1}. However, the most dominant weed species varied over time. During the first 9 years, charlock (*Sinapis arvensis* L.), spurry (*Spergola arvensis* L.) and red shank (*Polygonum percicaria* L.) were very frequent, whereas field thistle (*Cirsium arvense* Scop.) and couch grass (*Agropyron repens* L.) tended to dominate during the final 9 years. During years with grassland, dandelions (*Taraxacum vulgare* L.) were common. Assuming an N concentration of 1.5% in dry matter, the presence of on average 1000 kg DM ha^{-1} weed biomass in the organic system contributed to a withdrawal of 15 kg N ha^{-1} yr^{-1} from the main crop.

In the unfertilised and conventional systems, the weed biomass was significantly lower ($P < 0.05$) than in the organic system, amounting to on average only 27 kg DM ha^{-1} and yr^{-1}. In contrast to the organic system, weed biomass decreased by about 5 kg DM ha^{-1} yr^{-1} in the unfertilised and conventional systems during the 18-yr period. The uptake and withdrawal of N by weeds in the conventional system was negligible (<1 kg N ha^{-1} yr^{-1}).

These results suggest that weed biomass can be a yield-decreasing factor in organic cropping systems.

7. CONCLUSIONS

The results presented in this overview clearly show that the use of green and animal manures in organic cropping systems results in lower crop yields, with no benefit for water quality. Therefore, claims about sufficient food supply and improved water quality associated with the use of manures in organic cropping systems should be viewed with great caution. In terms of N, we were able to identify two main reasons for this: (i) a lack of synchronicity between release of N from legume residues, animal manures and other organic N sources, and demand for N by the main crop; and (ii) a high release of N from such organic sources during periods without a crop. Build-up of a large weed biomass can also be a contributing factor to yield depressions in organic systems, as exemplified by results from long-term comparisons of conventional and organic cropping systems.

From the points listed, we can conclude that the most critical consideration in efforts to reduce N leaching from agricultural soils in cold and humid climatic regions is to supply the crop with N when it is needed and to avoid surplus amounts of N in soil during autumn/winter when no crop is growing. One way of reducing surplus N in soil during autumn/winter is to use cover crops. In one of the studies presented here, the smallest N leaching load by far was recorded in a conventional system with a ryegrass cover crop. This system also had the highest yields of comparable crops in the conventional and organic systems. In fact, the use efficiencies of N and P estimated for an 18-yr period were higher in the conventional system than in the organic.

It can be concluded that the use of countermeasures such as cover crops efficiently reduces N leaching losses within conventional agriculture and maintains high crop yields, but not a change-over to low-yielding organic cropping practices, which require more land.

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