Nutrients in Organic Farming – Are there advantages from the exclusive use of organic manures and untreated minerals?

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Abstract

Nutrient additions on organic farms are designed to maintain soil fertility, but not to directly feed plants. Hence, nutrients are applied in organic or low solubility inorganic forms in the belief that plants will obtain balanced nutrition through the actions of soil microbes. This review examines the implications of organic farming fertiliser practices for the sustainability of farming systems using two contrasting regions, Europe and Australia. In both these regions, mean yields are generally 20-45% lower on organic farms than conventional farms primarily due to reduced levels of plant available nutrients. Changes in the soil biological community do not overcome this limitation. Nutrient inputs are lower on organic farms, although in Europe there is a tendency on organic farms for increased application of purchased, approved, nutrient sources other than fodder. However, these inputs simply allow organic farms to gain nutrients that originated from conventional farms. If organic farming were to be widely adopted, lower yields would require more land (25-82%) to sustain production. In Europe, organic practices increase nitrate leaching, both per unit area and per unit of food produced, due to lower N use efficiency. Despite their aim of maximizing nutrient recycling, organic farming systems recycle only on-farm wastes and approved food wastes, with most municipal wastes excluded due to concerns about pollutants. In future, easily soluble inorganic fertilizers will be extracted from organic wastes through new nutrient recovery technologies and this will make conventional agriculture more sustainable whereas organic farming excludes itself from non-farm recycling, no matter how environmentally clean and safe the new fertilizer products are. In conclusion, the current promotion of organic principles irrespective of environmental outcomes means organic farming has become an aim in itself. This approach is ideological, not scientific, and may exclude other more effective solutions to the environmental problems afflicting current agricultural systems.

Media Summary

Expectations about the superiority of organic farming methods with respect to nutrient use efficiency, soil fertility, nitrate leaching and nutrient recycling are not justified by scientific studies.

Key words

Nitrogen input, Soil fertility, Yield, Waste recycling, Rock phosphate, Nitrate leaching, Nutrient recycling, Fertilizers

Introduction

How is plant nutrition viewed in organic farming philosophy?

The exclusion of synthetic fertilizers in organic farming has been motivated by various arguments. Steiner (1975), the founder of bio-dynamic farming, stated that “any addition of mineral fertilizers affects crops in such a way that they lose their nutritional value”. Balfour (1943), the founder of the Soil Association, believed that “artificial fertilizers speed up the rate at which humus is exhausted”. Howard (1947) argued “agricultural research with inorganic fertilizers is misleading. The great nature law of return, birth-growth-reproduction-death-decay is ignored”. Rusch (1978), the founder of biologic organic farming, argued that “artificial fertilization is not a normal, physiological and natural form of plant nutrition and that it is impossible to mimic the natural release of nutrients from soils to crops and this is the mistake of artificial fertilizers”. The Australian National Standard for Organic and Biodynamic Produce states that plants should be “fed through the soil ecosystem and not primarily through soluble fertilizers added to the soil such that the metabolism of the plant and its ability to assimilate nutrients is not overstressed by excessive uptake of soluble salts in the soil water” (AQIS 1998). Overall, philosophical views about life are the basis for such organic principles (Kirchmann 1994) with a (onesided) romantic view about nature as a whole – disregarding the large variations which occur in nature including unwanted/non-controllable conditions - predominating.

How is soil fertility maintained in organic farming?

As a consequence of the views listed above, application of soluble manufactured fertilizers is generally prohibited in organic farming systems. Instead, it is advocated that soil fertility be maintained through a variety of other means. These have been summarized by Watson et al (2002) as follows: (i) use of natural minerals; (ii) enhancement of N_2 fixation through appropriate types of ley and green manure; (iii) best recycling practice and efficient use of manures; (iv) enhancement of soil biological activity so as to increase weathering of minerals in soil and non-symbiotic N_2 fixation; and (v) creating a balance between the number of animals and the cultivated area. These practices reflect the primary aim of soil fertility maintenance in organic systems; to supply the soil but not directly feed the plant. They also reflect the wishful ideal of a farm being a self- sufficient unit based on recycling of local resources.

Purpose of this review

As we have pointed out, organic farming is based on the dogma (as opposed to an hypothesis) that the use of organic and non-synthetic forms of nutrients is superior to synthetic fertilizers and, accordingly, contributes towards: food of better nutritional value; increased soil fertility; conservation of resources; less environmental stress; and, overall, a more sustainable form of agriculture. In addition, the dogma regarding the superiority of organic methods has a philosophical dimension as there is a widespread belief in society that “natural” means are *a priori* better than others, a so-called “nature philosophy”. This review will examine whether the results from scientific studies reject or strengthen this dogma in relation to yields, soil fertility, nitrate leaching and closing of nutrient cycles, primarily using examples from broadacre agriculture in Europe and Australia. Whilst organic principles originated largely in northern Europe, they have been adopted around the world including in regions such as Australia with vastly different soils, climate, environmental issues and production systems. As social and political pressure builds up for even more widespread adoption of organic farming across the globe, it is important to critically examine its performance relative to conventional alternatives. This paper does not set out to examine all nutrient aspects of organic farming. In particular, the relative nutritional value of organic and conventional food is not discussed as several recent studies and reviews conclude that there are few consistent differences between organic and conventional food (Ames et al 1990; Woese et al 1997; Bourn and Prescott 2002; Ryan et al 2004a). Similarly, this review does not address the issue of consumer preference for organic produce and the impacts of such a preference on price premiums and profitability.

Stringent scientific comparisons

There is a tendency when presenting results from comparative studies of organic and conventional farms to assume that any differences occurring between systems are a consequence of the management factors that are dissimilar, namely the non-use of pesticides and exclusion of readily soluble inorganic fertilizers on organic farms. Thus, it is assumed that the results are generally representative of organic and conventional systems. However, differences may be caused by management practices that are potentially open to manipulation in a similar manner in each system and/or may vary greatly within one or both systems. For instance, the need for nutrient supply in organic farming may imply purchase of animal manures and for example of fish wastes. This can result in different soil C contents, soil microbial biomass, soil fauna, soil structure, N input and leaching between systems (e.g. Robertson and Morgan 1996; Lotter et al 2003). Stating that “soils on organic farms have higher C contents and sequester more carbon” and thus using the aggregated term ‘organic farming’ is a pseudo-explanation for the results gained. The real reasons explaining the differences would be the application of more organic matter on the organic farm, which while a reflection of organic ideology, is not mandatory and could also be done on a conventional farm applying sewage sludge, biogas residues or other cheap off-farm wastes. In this review we attempt whenever possible to delineate between the impacts of the requirement in organic farming for fertilizers to be in an organic or poorly soluble inorganic form, and the impact of other variations in management practices.

Yields on organic farms

What yields are achieved on organic farms and what area of land is required to sustain them?

A number of long-term field trials in Europe reveal that crop yields are on average 20% lower in organic systems that combine crops with animals and 33-45% lower in organic systems with crops alone compared to their conventional counterparts (Table 1). The impact of the addition of animals reflects a greater degree of on-farm recycling of nutrients through animal manure and lower removals of nutrients from the system.

Studies of farms under long-term organic management in Australia also reveal yields of individual crops as substantially lower than on conventional neighbours (Table 1). In both Europe and Australia, the lower yields reflect either a lower fertilizer input (fertilization intensity) and/or a lower uptake efficiency of nutrients from fertilizers (see section on soil fertility). Similarly, a survey of maize yield on commercial and organic mixed crop-animal farms in the USA in the 1970s found yields to be 8% lower on the organic farms (Lockeretz et al 1980).

Lower yields in individual years must also be placed in the context that organic farms often require a longer pasture ley or use green manures to build-up soil N prior to cropping, that is, individual paddocks may be sown to crops a smaller percentage of the time than in an equivalent conventional system. For instance, in Table 1 the Australian organic wheat crops were preceded by an average of 4.7 years of pasture, compared with 3.3 years for the conventional crops (Ryan et al 2004a). Also, yields reported for organic management may overestimate long-term productivity due to residual soil nutrients. For instance, in relatively fertile soils a decade or more may be needed without any fertilizer addition before residual soil nutrients are sufficiently exhausted for a yield penalty to become apparent (Denison et al 2004).

The low yields on organic farms mean that to produce the same amount of food as conventional farms, more land is needed. For instance, to sustain food production in Europe, widespread adoption of organic farming without animals would require an increase in land area of 64%, assuming crop production is reduced by 39%, and adoption of organic systems with animals would require an increase in land area of 25%. Indeed, for Danish dairy farming, Halberg and Kristensen (1997) concluded the area farmed would need to be extended by 47% to sustain yields with conversion to organic production. As Borlaug and Dowswell (1994) and Avery (1995) pointed out "growing less food per acre leaves less land for nature". If conventional farming is widely replaced by organic farming, clearing of wildlife habitats and conversion of natural and semi-natural ecosystems into agricultural land is unavoidable in systems that did not originally produce a food surplus. This would increase the proportion of man-made ecosystems in the world with a corresponding negative impact on conservation of biodiversity. From a global perspective, biodiversity cannot be conserved through more organic farming.

Soil fertility

How intense are the nitrogen inputs to organic farming systems?

The mean N input to the European organic long-term experiments in Table 1 was lower in the organic (95 kg N ha^{-1}) than in the conventional systems (170 kg N ha^{-1}). A number of other case studies of N flows on organic farms (Kaffka and Koepf 1989; Fowler et al 1993; Nolte and Werner 1994; Granstedt 1995; Nguyen et al 1995; Fagerberg et al 1996; Wieser et al 1996) also reveal lower mean N inputs to organic (90 kg N ha^{-1} yr^{-1}) than conventional systems (165 kg N ha^{-1} yr^{-1}) over a whole crop rotation period. However, yearly N inputs ranged from zero to several hundred kilos per hectare on organic farms with high inputs from N_2 fixing crops followed by years with little or no N input. Thus, the N input in organic farming tends to be quite imprecise, being unevenly distributed in the crop rotation and not necessarily well-adapted to the needs of the following crop. Table 1 shows for the Norwegian site that the percentage of N input reduction (53%) is greater than the percentage of yield reduction (22-26%). This may indicate that N was used less efficiently in the conventional treatments. In fact, the soil organic matter content at this site is declining in all treatments being largest in the organically treated soil (Korsaeth and Eltun, 2000). The relatively high N mineralization may not require the high N fertilization intensity at this site.

Table 1. Mean yields from long-term organic and conventional farming system experiments in Europe and from commercial cropping-livestock farms (one pair) and irrigated dairy farms (ten pairs) under long-term organic or conventional management in Australia.

Experiment and farming system	Yield (t ha^{-1})		Yield decrease (%)	N input (kg ha^{-1} yr^{-1})		Reference
	Organic	Con.		Organic	Con.	
Norway: Apelsvoll-site (8 yr)						
Crops plus animals				121	227	Korsaeth and Eltun (2000) Eltun et al (2002)
Barley, oats, wheat	3.7	5.0	26			
Three-year forage crop	8.3	10.7	22			
Green fodder	7.1	7.6	7			
Switzerland: DOK-trials (24 yr)						
Crops plus animals				105	138	Spiess et al (1993) Besson et al (1999) Mäder at al (2002)
Winter wheat	4.1	4.5	10			
Three-year forage crop	11.5	14.0	18			
Potato	30.0	48.0	38			
Sweden: Skåne-trials (12 yr)						
Crops only				59	130	Ivarson and Gunnarsson (2001)
Winter wheat	3.7	6.3	41			
Potato	21.4	38.0	44			
Crops plus animals				110	185	
Winter wheat	4.1	6.4	36			
Two-year forage crop	6.6	9.3	29			
Australia: New South Wales (30 yr)						
Crops plus animals				0	17^	Ryan et al (2004a)
Wheat§	2.9	5.5	48			
Australia: Victoria (17 yr)						
Animals only				0	17^	Small and McDonald (1993)
Milk (L ha^{-1} year^{-1})*	6740	9060	26			

§ Organic wheat was fertilized with 18 kg ha^{-1} yr^{-1} of P as rock phosphate and conventional wheat with 16 kg ha^{-1} yr^{-1} of P as di-ammonium phosphate (average grain yields over 3 years from a farm pair where one farm had been under organic management for 30 years).
* Conventional pastures received 27 kg ha^{-1} yr^{-1} of P as soluble synthetic fertilizers while biodynamic pastures received no P (average milk yields over 3 years from 10 paired farms where one farm in each pair had been under biodynamic management for an average of 17 years).
^ N inputs from legumes not included in calculations, only N directly applied in fertilizer.

How efficient are commercial fertilizers approved for organic agriculture?

Field experiments with approved organic fertilizers in Europe showed meat bone meal and chicken manure increased grain yields only moderately (600 to 1500 kg ha^{-1}) compared to an unfertilised control, at application rates of 40 to 120 kg N ha^{-1} (Lundström and Lindén 2001) (Table 2); N-utilization was also considerably lower (30%) than for inorganic synthetic fertilizers (60-80%) (Mattsson and Kjellquist 1992). In an earlier study of spring wheat fertilized with meat bone meal, N-utilization was only 13% (Wivstad et al 1996). To market wheat as bread wheat, a minimum protein content of 9.5% is required in Sweden and, on average, this was not reached in treatments using the approved organic fertilizers at rates of 40 or 80 kg N ha^{-1} to winter wheat.

In southern Australian cropping systems, where growing-season rainfall may be as low as 250 mm and soil extractable bicarbonate P less than 20 mg kg^{-1}, organic farmers rely on rock phosphate to supply P to organic crops which have N-requirements met through N-fixation in a preceding legume-based pasture ley. However, in this environment, rock phosphate provides no immediate benefits to crop P-nutrition or growth (Ryan et al 2004a). The resulting P-deficient status is, along with high weed levels, the primary cause of substantially lower yields in organic compared with conventional systems (Kitchen et al 2003; Ryan et al 2004a) (Table 1). Overall, reliance on untreated minerals and organic fertilizers on organic farms often results in lower yields than can be achieved with synthetic fertilizers, particularly in regions where native soil fertility is low.

Table 2. Yield and nitrogen utilization of cereals with approved organic fertilizers in Europe.

Organic fertilizer (N-P-K composition); Number of trials (n)	Crop yield increase, over an unfertilized control (kg ha^{-1}) at different N application rates	Mean crop N utilization by yield (%)	Reference
Meat bone meal (Biofer) (10-4-0); n = 4	Spring wheat 300 (57 kg N)	13	Wivstad et al (1996)
Meat bone meal (Biofer) (11-3-0); n = 15	Winter wheat 430 (40 kg N) 800 (80 kg N) 1180 (120 kg N)	30	Lundström and Lindén (2001)
Chicken manure (Binidan) (6-3-12); n = 15	Winter wheat 560 (40 kg N) 1080 (80 kg N) 1510 (120 kg N)	30	Lundström and Lindén (2001)
Inorganic N fertilizers n = 152	Winter wheat 1690 (40 kg N) 3150 (80 kg N) 4360 (120 kg N)	60-80	Mattsson and Kjellquist (1992)

Can an enhanced soil biological community improve availability of plant nutrients in organic systems?

It is often assumed that the soil biological community will be enhanced in response to organic management, developing a greater capacity to supply plants with nutrients from poorly soluble inorganic and organic sources (Ritz et al 1997). However, if organic systems do not include larger inputs of organic matter than conventional counterparts, or if organic production is limited by low fertility, the soil biological community and its activity will not be enhanced relative to conventional systems (Ryan 1999). Indeed, soil organic matter contents have been reported as higher (Reganold 1988; Wander et al 1994; Liebig and Doran 1999), lower (Lützow and Ottow 1994; Petersen et al 1997) or to not differ (Derrick and Dumaresq 1999) in organic compared to conventional systems. This variety reflects different crop sequences and/or addition of different amounts and types of organic inputs (Robertson and Morgan 1996). Higher addition of organic matter in either system is naturally followed by a larger microbial biomass (Gunapala et al 1998; Fliessbach and Mäder 2000). There is no evidence that a larger microbial biomass will change basic relationships in soils (Kirchmann et al. 2004) such as those between concentrations of soil available nutrients and plant nutrient uptake and growth (Ryan 1999; Ryan and Ash 1999; Ryan et al 2000); although addition of organic matter may, in some instances, suppress disease-causing organisms (Sivapalan et al 1993).

One component of the soil biological community that is consistently more abundant on organic farms is arbuscular mycorrhizal fungi, as soluble P fertilizers suppress their occurrence on conventional farms (Miller and Jackson 1998; Ryan et al 2000). Arbuscular mycorrhizal fungi are best known for their ability to enhance host plant uptake of P and other nutrients (Smith and Read 1997). However, studies of organic crops and pastures in southern Australia show that high colonisation does not overcome the serious P-deficiency experienced in these systems (Ryan et al 2000; Ryan and Angus 2003). Indeed, as the fungi obtain all carbon requirements from the host plant (Smith and Read 1997) and supply no return nutritional benefits, in this instance they may act as a parasite on crops, reducing crop yield potential (Ryan et al 2004b). Arbuscular mycorrhizal fungi may play a positive role in growth of organic crops in other regions (Thompson 1987; Gaur and Adholeya 2000). However, as the fungi only can facilitate uptake of P already present in a system, P-fertilizers will also be required. The generalization that organic practices automatically stimulate an enlarged soil biological community, and that this can partly substitute for inorganic fertilizers, is inaccurate (Ryan and Ash 1999).

Are soil nutrients depleted by long-term organic farming?

Phosphorus and K balances of organic systems indicate that more of these nutrients are removed through harvested products than applied to soil (Kaffka and Koepf 1989; Spiess et al 1993; Fagerberg et al 1996; Ivarson and Gunnarsson 2001). Farm-gate balances also indicate a greater output than input of nutrients in organic agriculture (Fowler et al 1993; Nolte and Werner 1994; Granstedt 1995), although not if sufficient volumes of approved organic manures are purchased (Nyberg and Lindén 2000). For instance, reduced concentrations of plant available P and K were measured in nutrient-rich soils in Norway within five years of conversion to organic practices by Løes and Øgaard (1997) and in Denmark, Askegaard and

Eriksen (2000) reported K limited growth of barley and clover ley crops on sandy soils after only a few years of organic farming. In the United Kingdom, Berry et al (2003) examined nine organic farms and found additions of rock phosphate and imported animal feed provided large amounts of P and K but, even so, K budgets were negative on most farms, particularly those without animals.

Rock phosphate is also used to maintain a positive P balance on organic farms in Australia and New Zealand, but low soil available P relative to conventional neighbours is still common (Nguyen et al 1995; Derrick and Dumaresq 1999; Ryan et al 2000). Lockeretz et al (1980) also found evidence of reduced soil available P on organic maize farms in the US relative to conventional counterparts. Overall, there is a substantial risk of nutrient depletion in organic systems with a directly associated reduction in yield. Moreover, nutrient deficiencies may also feed-back through the system and limit other processes which indirectly impact on yield. For instance, Derrick and Ryan (1998) found that, compared to a conventional neighbour, grain from a P-deficient organic farm had a low P content and, consequently, poor seedling vigour. As high levels of weeds were present in the organic crops (Ryan et al 2004a), poor seedling vigour, and a reduced capacity to compete with weeds, may have had a serious impact on yield.

Nitrate leaching

Lower mean N input in organic farming – Does it result in less nitrate leaching?

It has been postulated that organic farming reduces nitrate leaching, a major environmental concern in Europe (Koepf 1973; Kristensen et al 1995; Drinkwater et al 1998). Indeed, a comprehensive literature review showed that the average leaching of nitrate over a crop rotation was somewhat lower per unit area from organic systems than conventional systems (Kirchmann and Bergström 2001). However, a correct comparison of leaching between systems also requires yields to be considered and this was not accomplished due to differences in the sequence and type of crops grown, differences in the input intensity of N and a general lack of yield data (Kirchmann and Bergström 2001). Wrong interpretations of leaching data are common, as pointed out by Andrén et al (1999).

Table 3. Nitrogen input, offtake and leaching in organic and conventional long-term trials in Sweden.

Experiment and farming system	Organic			Conventional			Reference
	Input (kg N ha^{-1} yr^{-1})	Offtake	Leaching	Input (kg N ha^{-1} yr^{-1})	Offtake	Leaching	
Halland-site							
Crops only	66	30	43	99	79	29	Torstensson (2003a)
Crops plus animals	120	105	35	113	71	26	Hessel Tjell et al (1999)
Västergötland-site							
Crops only	105	42	20	113	85	3	Torstensson (2003b) Lindén et al (1993)
Mean	**97**	**59**	**33**	**108**	**78**	**19**	

In a series of Swedish long-term field lysimeter trials that commenced in the early 1990s, similar crop rotations in the organic and conventional system were maintained except in years when green manure was grown (Torstensson 2003a,b; Hessel Tjell et al 1999). Furthermore, mean N input in the organic systems was close to that of conventional systems (Table 3). In these studies, on both a sandy and a clay soil, organic systems had greater nutrient leaching and greater release of N and P (data not shown) to drainage water both per hectare and per unit of harvested N. To clarify the efficiency of N use in the organic and conventional systems, N uptake through yields and N lost through leaching water were expressed as a percentage of the sum of both. The proportion of the two outputs measured was 35% of N leached and 65% taken up by crops in the organic systems compared to 19% leached and 81% taken up by crops in the conventional systems (denitrification was not determined). These experiments indicate that if differences between comparative studies caused by different crop rotations and N input intensity can be largely eliminated, leaching of N from organic systems is not lower per unit area. It appears that the asynchrony of crop N demand and N release from manures compared to inorganic synthetic fertilizers is the major cause for the higher leaching losses from organic systems, as more manure N remains in the soil after application and is mineralized at times when there is no crop demand (Bergström and Kirchmann 1999; 2004). Green manures may, in a similar manner, also cause large nitrate leaching losses (Wallgren and Lindén 1991; Watson et al 1993) and much higher leaching of P than inorganic synthetic fertilizers (Torstensson 2003b; Lindén et al 1993).

Closing nutrient cycles

Can nutrient cycles be closed in agricultural systems?

All forms of agriculture involve removal of plant nutrients via harvest of plant material. One major criterion for the sustainability of farming systems is the proportion of nutrients recycled back to the soil. Indeed, there is a widespread belief, as proposed by Steiner (1975), that self-sustaining farms are the real core of sound agricultural production. This is reflected in the view that optimal measures to maintain nutrient levels in agricultural soils involve a high degree of recycling of nutrients with any small losses balanced by soil weathering. Traditional agricultural systems in Europe and elsewhere are held up as an ideal in this context. However, examples of nearly self-sustaining farms, or indeed agricultural systems, are rare (Nolte and Werner 1994; Newman 1997).

King (1911) described agricultural practices and, in particular, waste recycling in China, Korea and Japan. He concluded that agriculture was being practiced in a far more sustainable form than found in the USA due to the equitable redistribution of nutrients present in human latrine waste, composted household wastes and ashes, as well as the application of sediments from ditches, and other natural resources, to agricultural land. Agricultural history in Europe also tells an instructive story. The mechanism behind the build-up and maintenance of Plaggen (organic matter enriched) soils was the transfer of plant nutrients through soil and litter from natural ecosystems (heathlands, wet grasslands, meadows) to arable soils for several hundred years (Pape 1970; Pott 1990; Springob and Kirchmann 2002). Thus, along with careful nutrient recycling, nutrient depletion of natural ecosystems was necessary to maintain yields. In the very long-term, any agricultural system will become depleted in nutrients, particularly phosphorus, unless there is a regular addition from an external source (Newman, 1997). Situations where this occurs without human intervention, for example silts deposited in annual floods, appear rare (Newman, 1997); certainly not common enough to produce adequate food for an increasing world population.

Nutrient recycling in industrialized countries

In industrialized countries, nutrient cycles are currently far from closed and there is no doubt that improvements should be made to improve the overall sustainability of agriculture systems. In these countries, nutrients removed from a field can flow through three cycles - the industrial cycle, the fodder cycle and the food cycle (Fig. 1). The potential to close nutrient cycles is discussed below using Sweden as a case study.

In the industrial cycle, wastes from food and related industries using agricultural products, may be recycled as fodder (e.g. brewer's and distiller's grains, whey, beet- and potato pulp, molasses, oil seed cake). In addition, a variety of wastes (e.g. waste lime, starch industry residues, meat meal, different sludge), although quantitatively of minor importance, are often locally recycled on arable land.

The fodder cycle involves the flow of nutrients through housed animals, on- or off-farm, and results in manures, slurries, urine, feed lot wastes and deep litter wastes. These are traditionally recycled to arable land. While organic farmers are encouraged to recognize on-farm animal wastes as a valuable source of nutrients, an emphasis on composting animal manures may cause large losses of ammonia-N during storage (Kirchmann 1985). Efficient methods to decrease ammonia volatilization from animal wastes have been developed within conventional farming (Bussink and Oenema 1998; Gustavsson 1998) and involve covering slurry and urine tanks, incorporation of animal wastes into soil within four hours after spreading, direct ground injection and regulation of manure storage and handling.

The food cycle concerns human consumption of food of plant or animal origin and the resulting municipal wastes such as sewage sludge and organic household wastes in form of compost or biogas residues.

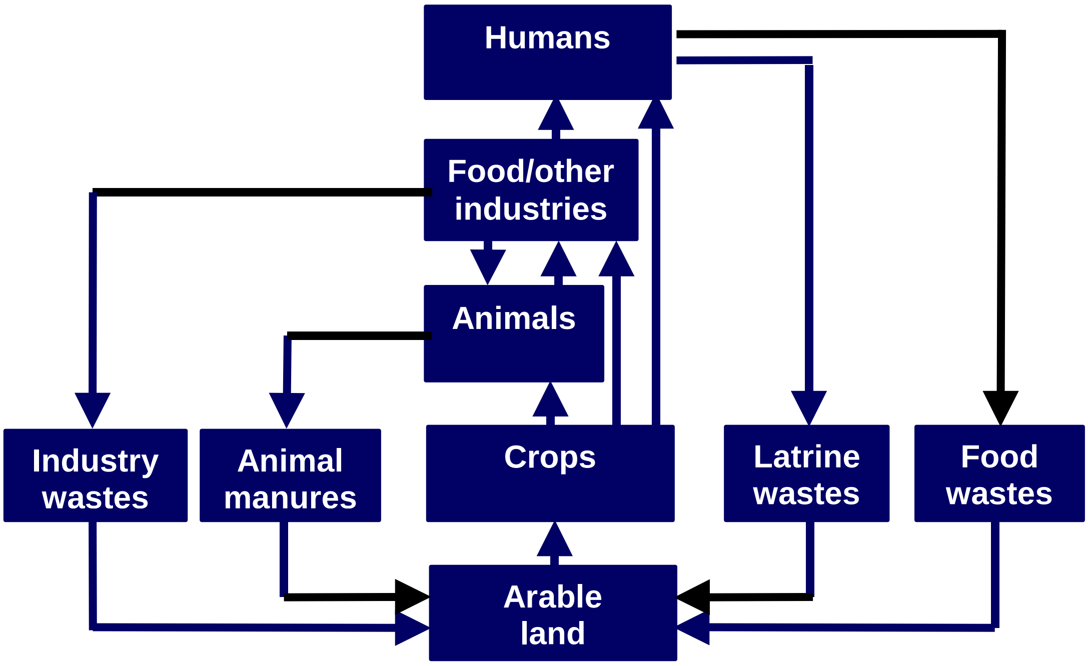

Figure 1. Recycling of plant nutrients through wastes derived from the industrial, fodder and food cycles.

Table 4. The amounts of nitrogen and phosphorus potentially able to flow through the industrial, fodder and food cycles in Sweden in 1999.

Human population numbers[a]		Total population	8 900 000
		Population with full waste service[b]	7 832 000 (88%)
Livestock numbers[c] **(LSU)**[d]		Total number of animals	1 869 466
		Number of crop-fed animals	1 827 805
		Number of grazing animals	41 661 (2%)
Plant yields[c] (t year^{-1})		Ley pasture and forage crops	6 000 000
		Bread and coarse grain	5 000 000
		Sugar beet	2 752 600
		Potatoes	990 800
		Oleiferous crops	130 000
		Leguminous crops	81 800
Nutrients in plant yields[d, e] **(t year^{-1})**		Nitrogen	221 400
		Phosphorus	35 500
Potential N and P in wastes (t year^{-1})			
Industrial cycle	Industrial food/crop wastes[f]	Nitrogen	1 735
		Phosphorus	884
Fodder cycle	Animal wastes[f]	Nitrogen	141 600
		Phosphorus	26 600
Food cycle	Organic human wastes[*h,i*] (latrine)	Nitrogen	42 700
		Phosphorus	5 600
	Organic human wastes[*h,i*] (food)	Nitrogen	4 900
		Phosphorus	1 200
Total N and P in wastes (t year^{-1})		**Nitrogen**	**190 935 (86%)**
		Phosphorus	**34 284 (97%)**

A Nordic Statistical Yearbook (2001).
b Swedish Yearbook of Agricultural Statistics (2000).
C Swedish Yearbook of Environmental Statistics (2000).
d Livestock Standard Unit. 1 LSU is equivalent to 1 dairy cow or beef cattle, 1.9 horses, 2.6 calves, bulls or heifers, 1.3 sows, 6.5 pigs, 9.4 sheep or goats, 170 poultry.
E Calculated using mean nutrient concentrations (Svanberg 1971).

F Data from Lammel and Kirchmann (1995).
G Calculated using nutrient excretion data for each type of farm animal (Steineck et al 2000).
H Nutrients excreted per capita (Geigy Scientific Tables 1981; SNV 1995) were multiplied by population size.
I Organic household wastes produced per capita and their nutrient content (Berg 1991; Rylander 1991; SNV 1993; Kirchmann and Widén 1994) were multiplied by population size.

The flows of N and P through the industrial, fodder, and food cycles in Sweden are summarized in Table 4 (Kirchmann 1998). Annual removals of plant nutrients from soil through harvested crops or by grazing were derived from national agricultural statistics. The amounts of nutrients potentially able to be returned through the three cycles (Fig. 1) were calculated from statistical data on: (i) the total number of farm animals and their nutrient excretion, excluding losses during handling and storage; (ii) the size of the human population and average excretion of nutrients via urine and faeces excluding losses; (iii) the size of the human population and average production of household food wastes excluding losses; and, (iv) the production of industrial crop and food wastes from various sources.

Overall, around 86% of harvested plant N and 96% of harvested plant P could potentially be recycled back to agricultural land. These figures contain some degree of uncertainty as data on import and export of food and fodder to and from Sweden were not available. Proportionally the largest part of harvested plant nutrients that ended up in wastes was present in animal wastes (around 75%), with 20-25% in human organic wastes, and less than 1% in industrial crop and food wastes. As animal wastes are traditionally recycled to arable land in Sweden, it is mainly nutrients present in the food cycle that are withdrawn and not returned to arable land. We envisage that a similar situation exists in other industrialized countries including Australia.

Is nutrient cycling enhanced by organic farming?

There is no doubt that the sustainability of most agricultural systems could be improved through an increased emphasis on recycling and greater return of nutrients in municipal wastes and off-farm products. However, losses via the food cycle would not be lessened through widespread adoption of organic farming as current regulations within the organic movement do not allow use of urban wastes due to concerns about contamination with metals and organic pollutants.

To improve recycling of nutrients and reduce the risk of contamination with pollutants, new recovery technologies to extract nutrients out of wastewater and biogas residues, and other municipal wastes are currently being developed. For example, P extraction can be done by precipitation as (i) calcium phosphate (van Dijk and Braakensiek 1984; Eggers et al 1991; Seckler et al 1996 a,b,c; Angel 1999), or (ii) magnesium ammonium phosphate (struvite) (Battistoni et al 1997; Liberti et al 2001; Ueno and Fujii 2001). Also, ultra micro filtration of liquid organic wastes may be used as a pre-treatment separating organic matter and solutes by polymeric/ceramic membranes (Cicek 2003). Nutrients present in separated solutions can thereafter concentrated by different methods such as ion exchange, evaporation or reverse osmosis. Overall, the redistribution of the recovered nutrients in form of concentrated, water-soluble, inorganic products may help to overcome the main bottlenecks for recycling of nutrients from municipal wastes, namely high costs for long-term transportation of wastes produced in towns and cities back to rural areas and low attractiveness of municipal wastes due to low nutrient contents and presence of organic pollutants and toxic metals. This may be of particular importance in countries such as in Australia where much production is located long distances from population centers and processing industries. However, as nutrient recovery technologies are moving towards easily soluble, inorganic products, only conventional farmers can benefit from the fertilizer products that will be produced from municipal waste.

Flow of nutrients from conventional to organic farming

To maintain soil fertility, organic farmers purchase approved organic fertilizers. In Europe, these fertilizers generally originate from conventional production. In fact, there is an increasing trend in organic farming in Sweden to apply nutrients of off-farm origin via approved organic fertilizers such as meat meal, bone meal, poultry manure and wastes derived from food industries (Swedish Control Organization for Alternative Crop production, personal communication). This is an indirect transfer of nutrients originating from conventional production and creates a reliance on production systems fertilized with inorganic fertilizers (see Berry et al 2003). Health risks arising from using slaughter-house wastes (mad-cow disease) in organic farming are currently not considered in Sweden.

An EU regulation will prohibit the use of conventionally grown fodder within organic animal production after August 2005 (European Communities 1999). On the other hand, there are practically no restrictions on the use of organic fertilizers such as animal manures derived from conventional farms and on by-products from food processing industries (meat meal, blood meal, bone meal, residues from fish industries, canning industries etc). Thus, organic farmers can continue to rely on the import of nutrients from conventional production through purchase of organic manures. For example in Sweden, the amount of animal manure that can be purchased by organic farmers from conventional farmers can be 1.5 times the amount of nutrients sold through agricultural products from the organic farm according to rules by the Swedish Control Organization for Alternative Crop Production (KRAV, 1999). Unless there are changes in the regulations, organic farming will remain dependent on nutrients derived from conventional farming; an approach that obviously would not be successful if a large proportion of farms converted to organic farming.

Nutrient cycling: conclusions

If it is assumed that: (i) “clean” municipal wastes are available for recycling; (ii) nutrient losses during treatment and handling of these wastes are minimal; and (iii) weathering provides plant available nutrients at rates similar as losses, then there is no doubt that a dramatic improvement in the sustainability of farming systems could be achieved. Nevertheless, even if nutrient recycling is greatly improved, most agricultural systems would still require supplementation with inputs of externally-sourced nutrients to replace unavoidable losses and achieve synchrony between the nutrient demand of crops and the supply of soils. The dynamics of nutrient availability for optimal crop growth needs as great attention as nutrient recycling and this condition is still not fulfilled through the three objectives outlined above.

In summary, the supply of organic manures, composts, fish residues, meat meal, sea weed etc may be sufficient for a minority of farmers. However, if organic farming was to be become the dominant form of agriculture, there would be a great movement of nutrients from natural systems to farming systems, an overall shortage of organic fertilizers and a decline in soil fertility.

Are organic fertilizer practices a sustainable option for developing countries?

Organic farming is increasingly being advocated for developing countries as the low input nature of organic farming has much in common with traditional agricultural systems in these countries. For instance, many parts of Sub-Saharan Africa have high levels of poverty and malnutrition and very low nutrient levels in soils (SSSA 1997). Farmers in this region are often forced to grow food in a manner consistent with organic principles due to the high cost and uncertain supply of inorganic fertilizers. However, advocating reliance on organic principles under these circumstances is not necessarily wise. Many African farming systems have an extremely poor resource base. The focus on organic resources and the refusal to include synthetic fertilizers can be best described as ‘recycling poverty’ (K.E. Giller, personal communication). Poor soil fertility can only be slightly improved with organic resources if there is enough organic material available, which is not the case in ecosystems on highly leached and nutrient poor soils. Organic materials can serve as basal fertilizers, whereas only mineral fertilizers ensure synchrony with crop demand (Palm et al 1997). While high-reactive rock phosphates can be practical and cost effective for the replenishing of P in very acid soils, they may not be effective under other soil conditions (Buresh et al 1997). As in the Australian situation discussed earlier, more reliable results would accrue from careful use of inorganic P fertilizers. In addition, many African soils are also deficient in other plant nutrients including copper, zinc, magnesium, and calcium (Mugwira and Nyamangara 1998). Adequate supply of these is required to improve crop production and, in some cases, to ensure adequate supply of essential elements to the population (Gibson 1994).

Conclusions

A major requirement of organic farming is that plant nutrients be added in organic forms or as poorly soluble inorganic minerals. The long-term fertility of soils can be maintained only if the output of plant nutrients is compensated by a comparable input. This is often not currently the case in organic agriculture for several macronutrients, in particular on farms without animals where removals are greater and inputs from supplementary feed do not occur. As soil nutrient reserves are depleted, large yield penalties will occur on organic farms. Even if the nutrients are replaced in fertilizers, they will often become only slowly available to plants. While the soil biological community on organic farms may differ from conventional farms, it will not compensate yields for the lack of readily available nutrients in fertilizers.

In addition, N use efficiency of organic manures can be lower than of soluble inorganic fertilizers and the release of nutrients from organic manure is not often synchronized with crop demand, resulting in greater losses than occurs with inorganic fertilizers. In terms of closing nutrient cycles, organic farming is currently limited by an inability to use municipal waste both directly or as inorganic extracts. Currently, organic farming systems are also often subsidized by the nutrients used in fertilizers on conventional farms, which are imported as fodder or manures.

In summary, organic farming has the many attractive ingredients of a 'nature philosophy', that is, the intrinsic goodness of nature, but when critical scientific analysis is applied the dogma of the superiority of organic farming fails. Organic principles do not provide a better long-term outcome in the search for sustainable forms of agriculture than conventional farming. Overall, we advocate a flexible approach where farming systems are designed to meet specific environmental, economic and social goals, unencumbered by unscientific dogmatic constraints (Kirchmann and Thorvaldsson 2000).

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