Dreams of Organic Farming

Facts and Myths

Holger Kirchmann, Lars Bergström,
Thomas Kätterer and Rune Andersson

Dreams of Organic Farming
Facts and Myths

Dreams of Organic Farming

Facts and Myths

HOLGER KIRCHMANN, LARS BERGSTRÖM,
THOMAS KÄTTERER AND RUNE ANDERSSON

Fri Tanke förlag
www.fritanke.se
info@fritanke.se

Editor: Jenny Tenenbaum
Art & Design: Miroslav Sokcic
Design cover: Holger Kirchmann
Cover photo: Holger Kirchmann
Translation: Deane Goltermann

ISBN 978-91-87935-81-7

Contents

Foreword

Why have we written this book?

Our book is intended to bring to the wider public a basic understanding of organic farming, in Sweden and more generally. While our research naturally has a local focus, we find the effects this type of agriculture has on food supply and the environment apply to the wider world from Europe and beyond.

Organic farming receives significant public attention with an assurance that this form of agriculture is good for the environment and provides safe, wholesome foods. This, in turn, has led to organic forms of production receiving public financial support in Sweden, as in other countries, mostly in Europe. In Sweden, national agri-environmental payments total EUR 50 million annually. Policy objectives have also been set, with a first objective to convert 20 per cent of total farmed acreage in Sweden to organic farming by 2010. Another is that public procurement of organic food for schools, hospitals, elderly care, and similar should be 25 per cent of all foodstuffs purchased. Consumers are also increasingly demanding organic foodstuffs hoping to get added value in the form of better product quality, while benefiting the environment.

But is this really so? Do consumers get better foodstuffs and a better environment when they buy organic? Are the wide-ranging political subsidies justified? Are organic foods free from toxins? Can organic production provide enough food? Are nutrient losses to our streams and rivers really reduced? Is organic farming climate smart? Is organic food more wholesome? These are the central questions we highlight and discuss in this book with reference to our own and other published research.

Today's society holds a general and strong distrust of modern large scale agriculture. Our book will regularly compare organic farming to conventional practice. We do not, however, see current conventional farming practices as sustainable, nor are they always environmentally friendly. We see that conventional agriculture suffers from problems and, indeed, has many shortcomings. Our book is intended as a factual compilation of the possibilities and limits of organic agriculture, not as a defence of conventional farming.

The discussion in our book is based on an objective presentation of research findings related to organic agriculture. We felt it important to ignore our own opinions, preconceptions, and any biased interpretation of the findings. In our research, we have worked to find better methods and effective solutions for problems linked to the environment that face modern agriculture. As well, most of us have previously believed that organic agriculture could be the future of farming.

We consider everything from the origins of organic farming, production of food and its quality, soil fertility, environmental impact, toxins in foodstuffs, and the risk of global and enduring food shortages. Finally, we present our views on what we believe provides the best possibilities looking forward achieving long-term sustainable food production that has the least possible negative environmental impact.

We want to thank our colleagues and families, who through their critical review of our text have helped us clarify, supplement, and restructure our text.

Holger Kirchmann, Lars Bergström, Thomas Kätterer and *Rune Andersson*

1

The rise of agriculture through the centuries

Agriculture means using and managing the soil for sustainable food production

Most everyone shares the view that nature should be used and preserved rich and fertile for coming generations. The concept of 'use and manage' has been a precept for utilising nature in many cultures. This leads to the conclusion that humans should only harvest what nature provides, through hunting, fishing, and gathering wild plants. But simply harvesting in this way would only be able to feed a limited number of people. Today, cultivation of plants is a prerequisite for humans to have enough food to eat. Still, this cultivation should be environmentally friendly and sustainable, and fertile lands should be handed over to coming generations. Globally, more than 90 per cent of our food is produced in agriculture, the rest is taken from the oceans.

Cultivating the earth, however, necessitates that previously natural lands have been transformed into farmland. Trees have been felled, bushes cleared, stumps and rocks removed, and wild plants replaced with productive varieties. These new fields are drained, worked, fertilized, lime-treated, and weeded. Crops are sown, and protected from parasite infestation. All these activities involve managing and controlling our nature in order to grow our food. As well, all our agricultural activities interact with the climate, the topography of the land, and the earth's parent material to build new soil types – what we now call agricultural soil.[4]

Farming, often referred to in older literature as cultivation, originally involved a significant intervention into the natural state. Wild plants, animals, and other organisms were suppressed when natural ecosystems were transformed into human-made agroecosystems. A drastic illustrative example is when rainforest is cleared to make way for farming soya or maize, causing large-scale reduction in diversity of existing plants and animals. In this light, it is important to note that slash and burn, and grassland farming, as a stage in the development of Sweden's agriculture (see below), has created highly species-rich ecosystems through establishing new living spaces for herbs, insects, and birds. Our point here is to foster understanding that from the beginning, agriculture involved a significant intervention into the natural state, and that agricultural systems are not natural ecosystems. All farming, including organic, presumes this basic transformation of the natural ecosystem.

Agriculture has created new man-made landscapes (bare soils, monoculture, fields with crop residues and stub, and pastureland) and equally, new living spaces have been created for many species. But agriculture has also removed the niches of other species. Without agriculture, forest would be the natural vegetation in most of Sweden – and then, mostly of spruce. Today, the extensive pastures that are similar to natural grasslands, are the most species-rich ecosystems created by agriculture.

> ***Agriculture is the result of the human control and management of nature to secure human food supply. Agricultural systems are not natural, but rather these are human created ecosystems. And, human created ecosystems can be more species rich than natural ones, as with flower filled pastureland. Though in today's world, this type of farming remains only on a very small scale.***

The history of agriculture revolves around the lack of, and the search for plant nutrients

Successful farming of crops requires fertile lands, which includes access to plentiful water and nutrients, loose soil structure, a favourable humus content, and soil that is not highly acidified. But, most natural and/or recently cultivated lands lack necessary plant nutrients and are highly acid, often limiting plant production.

Moreover, soil fertility is degraded by farming due to depletion – as plant nutrients are removed in the harvested products (Figure 1) plus losses due to leaching. This depletion from soils must be compensated for by adding corresponding inputs if soil fertility is to be maintained. History shows that the lack of, and the search for, plant nutrients to obtain greater yields, and to get nutritious crops, characterizes the development of agriculture, as in Sweden. The development of agriculture can be divided into four stages in relation to supplying crops with plant nutrients:[15]

Slash and burn (500 B.C to the 1800s)
Grassland farming (1700s – 1800s)
Crop rotation with forage (1800s – 1950s)
Modern fertilization farming (from the 1900s).

Slash and burn is the oldest cultivation system, and is still used in many developing countries. For this, fire is used in clearing and preparing land for farming crops. Ash from the burnt vegetation contains plant nutrients, which functions as fertilizer. The slash and burned lands provide high yields the first year, but even in the second year, yields decrease as plant nutrients in the ash have been utilised. Soon– when plant nutrient levels return to a normal, lower, state – the farmer will abandon this land and move to new areas only to slash and burn again to farm there. In Sweden, the land abandoned this way was often used as grazing land another few years before being left to revegetate. The slash and burn system successively expanded total farmed land area. This is how our current agricultural landscape emerged. Slash and burn, and grassland forms of farming existed side-by side up to the 1800s.[9,15]

Table 1 Yield per hectare of barley in Sweden for the period 1800 –1950.[8] Regional yield differences were minimal in the 1800s. By the 1930s, yields had increased by over 50 per cent as crop rotation became common, and by 1950, yields were doubled by adding mineral fertilizer.

County	Yield of barley* (kg per hectare)			
	1802–04	1892	1925–29	1950
Skåne	1000	1800	2500	3500
Kronoberg	800	1400	1600	2000
Östergötland	1100	1500	2100	2800
Värmland	1100	900	1300	1400
Uppsala	1400	1600	2000	2300
Gävleborg	1400	1500	1500	1600
National	**1050**	**1340**	**1860**	**2180**

*Barley was chosen to illustrate changes in yields since this crop has been grown across the entire country throughout the time periods shown on this chart, and were recorded in reliable statistics.

Grassland farming meant that harvested grass from meadows, pasture land, bogs, and forest were used as winter fodder for farm animals. Manure from these animals was then applied to crop fields, whereby plant nutrients from fodder producing back lands were transferred to farmed fields, giving rise to the Swedish saying 'ängen är åkerns moder, roughly meaning, meadows are the mother of cropland' referring to the addition of plant nutrients. The fertility of arable fields was maintained by application of manure, while the annually recurring harvesting of grasses from meadows led to these becoming depleted of plant nutrients. Still, grain yields on cultured fields averaged only 1,000 kilograms per hectare. The grassland area in relation to farmed fields determined the amount of plant nutrients that were added by way of fodder.

The share of grassland area for each hectare of farmland, for example, was greater in the central Swedish heartland of Svealand than in the southern region of Skåne, which was also reflected in higher yields (Table 1).

Crop rotation with ley, first implemented in the 1800s, meant that a portion of the grasslands were ploughed and converted to crop fields.[15] Forage plants, primarily red clover and grass (Timothy grass), were sown to grow 2 to 3 years of crops as winter fodder for the farm animals. Forage yields where higher and included more protein than yields from grassland. Clover in the forage added nitrogen from the air, which meant that having a large amount of forage in the crop rotation reliably improved the supply of plant nutrients. Winter fodder could now be mostly grown on farmed fields, but fodder was also imported from other parts of the world. Yields in general were significantly increased, and grain yields increased from 1,000 to 1,800 kg from the beginning of the 1800s (Table 1).

This type of farming, though, was still low in productivity despite the yield increase. The generally low plant nutrient levels in the fields could only be slightly raised, and despite the added nitrogen, most fields still lacked phosphorus and their pH condition was often low.

Degradation of soil minerals as a source for plant nutrients is a slow process and the amount of these released cannot counteract depletion of the fields. Crop rotation with clover and grass forage (and other nitrogen fixing legumes) as practised into the 1950s in Sweden, is strikingly similar to today's organic farming. Nitrogen is added by growing clover and legumes, and animal keeping is necessary in order to utilise the grassland forage. The manure also helps recycle plant nutrients to farmed fields, but if no plant nutrients are purchased from elsewhere, soil fertility cannot be maintained.

What are plant nutrients?

Plant nutrients are 14 elements essential for plants to live. These are taken up as soluble salts through the plant's roots. For example, phosphorus is taken up as phosphates and sulphur as sulphates. Regardless the type of fertilizer (organic or mineral), plants take up these substances in inorganic form as salts.

Macronutrients	
Nitrogen	N
Phosphorus	P
Potassium	K
Calcium	Ca
Magnesium	Mg
Sulphur	S
Chlorine	Cl

Micronutrients	
Iron	Fe
Boron	B
Manganese	Mn
Zinc	Zn
Copper	Cu
Molybdenum	Mo
Nickel	Ni

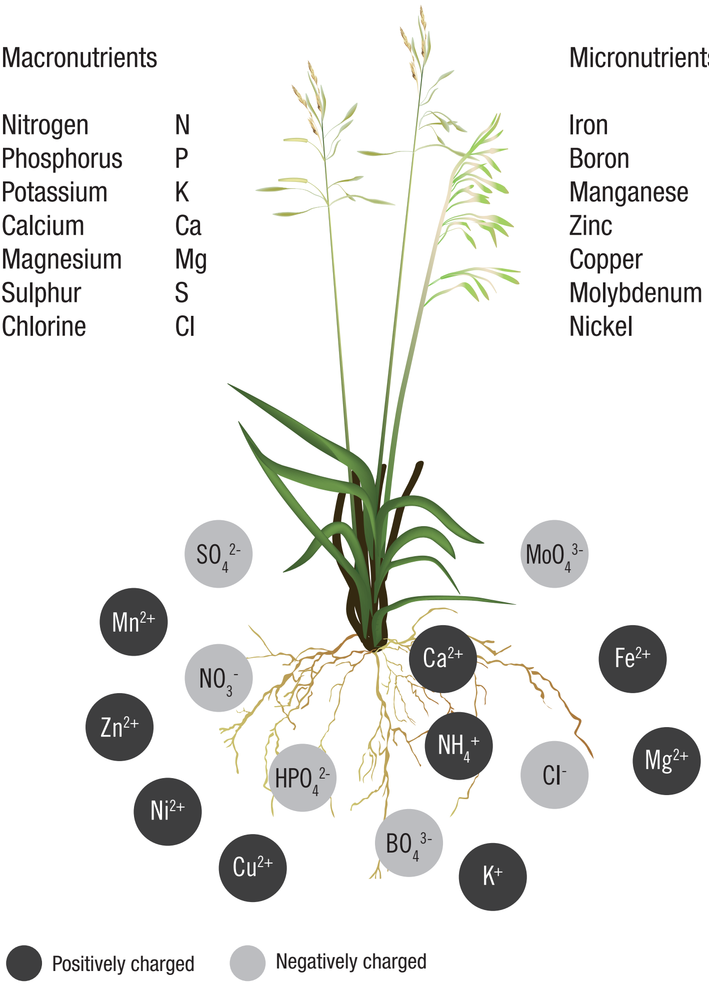


FIGURE 1. Necessary elements and mineral forms that plants take up.

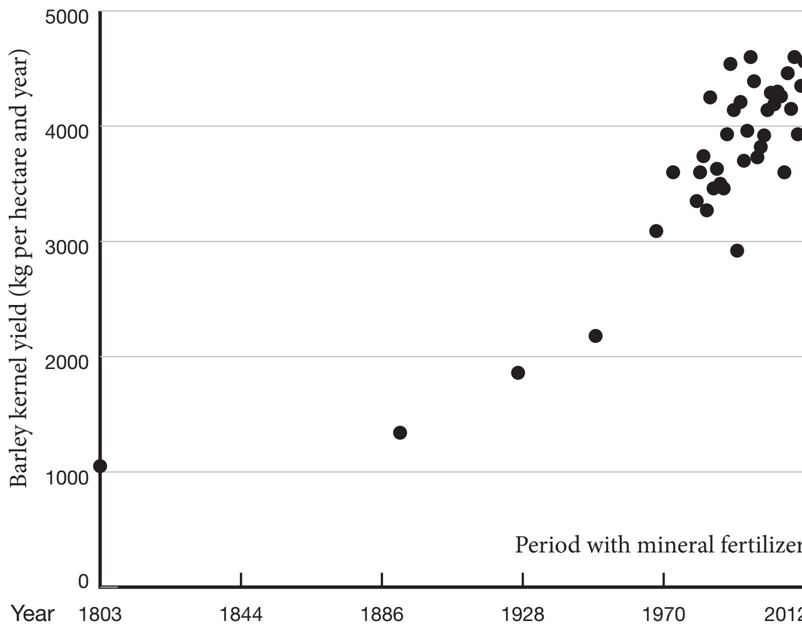


FIGURE 2. Yield trends of barley for the period 1800 to 2012.[8, 11] Since the 1950s, yields have doubled from 2,200 to 4,400 kilograms.

Mineral fertilization farming wasn't expanded until the 1950s. Around 1840, the German agriculture chemist Justus von Liebig discovered that plants could be grown without soil by dissolving several inorganic salts in water.[24] His discovery was that several elements in inorganic form were necessary for plants (Figure 1), not the mineral soil or humus. Understanding what minerals plants need led to determining which elements to include in fertilizer. One application was the manufacture of various types of fertilizer that, at first, were called chemical, or artificial, fertilizer rather than mineral fertilizer. Using chemistry, nitrogen gas from the air could be converted to ammonium nitrate.[18] Insoluble salts (raw phosphates) could be transformed into water soluble salts (superphosphates), which were then applied to the fields. The nutrient supply to plants could now be based on an understanding of their requirements for mineral elements, leading to the production of many types of mineral fertilizers.

In using mineral fertilizers, soils could be supplied with large amounts of plant nutrients, and Swedish farm fields were upgraded through the application of phosphorus and potassium.[6,7] Farmers no longer needed their manure, which meant that animal keeping and crop production no longer needed to be integrated in the same unit. Manure, previously a central link in supplying nutrients to crops, could now be replaced by mineral fertilizer. Yield per hectare then increased as nitrogen fertilization increased.[8] (Figure 2).

A new era began after the Second World War. Production on farms became more efficient and the structure of agriculture changed.[22,23] Fields were joined together into larger units and farms grew in size. Agriculture was mechanized with tractors, combine harvesters, and new agricultural tools (combined seed drill, incorporation of slurry, hay silage). Agricultural machinery became larger, which also increased efficiency in crop production. Sub-surface drainage was installed and other drainage blockages were removed. Water flow from the fields followed the path of least resistance to the nearest watercourse and lakes. The landscape became more uniform.

Using mineral fertilizer enabled specialization of farms towards either crop production or animal keeping. Instead of producing many different crops and keeping cattle, pigs, chickens, and horses on the same farm, farmers now could concentrate on only one product, but in larger volume, or they could focus on producing only cereals.

Production is also increasing in developing countries. Through plant breeding, high-yield varieties of wheat, maize, and rice have been created, which produce even higher yields with the help of mineral fertilizer. The ‘Green revolution’ is credited with saving billions of people from starvation.

Environmental problems

As we mentioned above, agriculture between 1950 and 1970 was primarily interested in increasing yields with the help of mineral fertilizers and with more efficient production.[7,8] This led to several negative effects: dead raptors, loss of bees and other beneficial insects, proliferation of specific weed species, algal blooms, mass fish-kills, overgrown ditches, increasing nitrate content in drinking water, pesticide residues in ground water, and a monotonous, species poor landscape.

Agriculture has always led to emission of undesired gases and nutrients into the environment, but this accelerated with the intensification of production. The impact of phosphorus leaching from the fields is especially noted due to its significance in relation to eutrophication of streams and lakes.

Pesticide residues in soils and water, and in crops, are highly concerning. Rachel Carson's seminal work, *Silent Spring,* published in 1962, first raised questions related to use of pesticides.[2] Carson exposed many of the negative effects on birds, and other life caused by application of pesticides, and criticized the use of toxins in agriculture. The subsequent public debate eventually led to banning use of perhaps the most controversial substance, DDT. This famous persistent chlorinated insecticide became the symbol for an environmentally toxic agriculture.

The other environmental problem, eutrophication of lakes and watersheds due to nutrients was linked to agricultural use of mineral fertilizers.[12] Leaching and run-off of nitrogen and phosphorus from fields contributes to algae blooms that can be toxic as such, and lead to oxygen depletion in these waters.

This led to growing scepticism of agricultural production methods and the use of mineral fertilizer and chemicals. Terms like 'mass production', 'artificial fertilizer', 'toxins in nature', 'pesticide residues' in food, and 'eutrophication' are now associated with agriculture. Our modern form of food production was often labelled an environmental villain, and large-scale agriculture was seen as a problem. The chemical components of this production came to represent an undesirable type of 'chemical' agriculture.

The growth of organic farming

As environmental problems related to agriculture were being identified, opinion grew in support of a more environmentally friendly type of farming, and organic farming was presented as a practical solution. Mineral fertilizer and pesticides simply would not be used.[5] Excluding these production aides was presented as the solution – the environment is spared and food quality improved.

These arguments, which are simple and sound logical, have also been expanded to include broader claims. Such as, the production of mineral fertilizer wastes finite resources. We do know that both fossil fuels and mineral resources are finite, and that conventional agriculture which is dependent on both of these, can therefore not be sustainable or promote conservation of resources.[5]

Moreover, mineral fertilizer enables the specialization of farms. These farms no longer need to keep animals to get their manure, but can instead buy fertilizer. This is how some farms can grow only cereals, while animal producing units simply become larger. This increases the need for animal feed, as animal farmers can no longer produce their own supply. They have to buy fodder from other specialised growers, which can lead to an excess of manure at the animal producing units. An imbalance in distribution of manure between farms can also be ascribed to the advancing use of mineral fertilizers.[4]

Many will listen to arguments for: No mineral fertilizer, No toxins, and Animals on every farm. Organic farming is growing in popularity, making it an increasingly credible alternative in wider circles. The assertion is that agriculture without mineral fertilizer or toxins addresses environmental issues at their source. Organic farming is then equated with being sound and environmentally friendly, with sustainable agriculture becoming a political mantra.[4] More consumers also demand organically farmed foodstuffs.

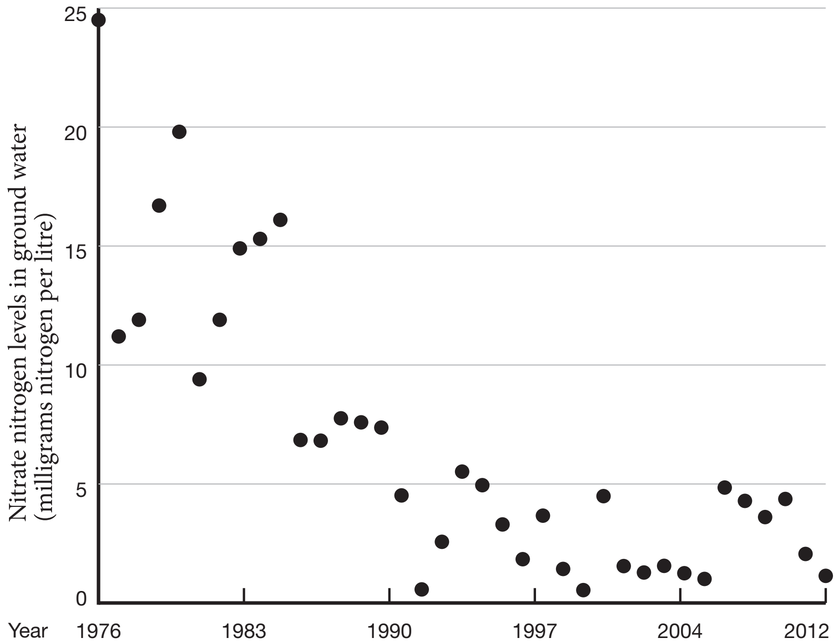


FIGURE 3. Reduction in nitrate levels in groundwater over time from an observation field in south Halland (southwestern coast of Sweden).[10,19] The leachate levels were measured 6 times every year, showing a decrease to less than 5 milligrams nitrate nitrogen per litre over time. This can be explained by regulations requiring maintaining growth on fields in autumn, and more environmentally sound application of manure.

Environmental management since the 1980s

The environmental issues related to agriculture had wide reverberations, shifting views of agricultural production at their foundation. This included that these environmental issues would have to be addressed. And involved a growing understanding that production and the environment must go hand-in-hand to enable sustainable food production. Using, and preserving nature are both equally important. Simply supporting agricultural production without driving environmental improvements becomes untenable.

New laws and stricter regulations were, and are being, developed by the Swedish Board of Agriculture and the Swedish Environmental Protection Agency, which have brought about improvements to the environment on farms and to how agriculture impacts the environment elsewhere. Environmental efforts have become a basic concept for Swedish society. An example is the 1999 national environmental objectives intended to achieve good quality in every type of natural environment.[16]

A popular preconception is that today's agriculture has developed with no consideration for the environment or for animal welfare. This is not the case. Swedish agriculture has transformed into a more environmentally sound form over the last 40 years. Mineral fertilizer is used to match the needs of the crop; pesticides are used under strict controls, and hazardous agents are banned; manure management is also strictly regulated. As a result, both nitrate leaching to groundwater, and seepage of chemical pesticides have been reduced significantly (Figures 3 and 4) – by a factor of ten due to directed environmental measures.

> ***Negative environmental impact from agriculture was the wake-up call of the 1960s. Since then, goal-oriented environmental efforts within Swedish agriculture have been implemented while organic farming has become more prevalent. Today, production and the environment are equally important in Swedish agriculture.***

Modern conventional agriculture is characterized by consistent, purposeful environmental action – with a regulatory background of the Swedish Environmental Objectives, the EU Water Directives and Nitrate Directives, the Plant Protection Products Regulation, the framework directive for the sustainable use of pesticides, manure management, and regulations to promote biodiversity. An extensive environmental monitoring system carried out by the Swedish Environmental Research Institute (IVL), the Swedish University of Agricultural Sciences, and the Swedish National Food Agency includes regular analysis of environmentally hazardous and other substances in the air, watercourses, drinking water, forests and farmland, and of crops. Long-term monitoring series and environmental statistics obtained now show improvement in the situation of Swedish agriculture, which is encouraging. This shows that people have learned from earlier mistakes, and addressed problems, and that measures based on science and technology can contribute to resolving these problems. Concrete examples include the measures implemented that we briefly describe here:

- Strict regulations were imposed on manure management to minimize nutrient loss and leaching related to storing and spreading manure. These cover 10 to 12-month storage periods to avoid spreading manure during the winter, and banning application to frozen ground.

- A limit to the number of animals permitted for each available hectare of farmed land was imposed to prevent excess use of manure on cropland. The main principle behind animal density is that no more than 22 kilograms of phosphorous per hectare and year may be applied as manure.

- Animal health has been addressed through stricter animal welfare regulations. This includes larger stalls, and better barn environment, cattle must be released for grazing in the summer, and eliminating transports lasting longer than 8 hours.

- The use of preventative antibiotics for livestock has been banned. Antibiotics therefore may only be used for veterinary treatment.

- Pesticides found to have strong negative environmental effects have been banned. Only approved pesticides, which are less toxic, may be used. The use of pesticides is made more restrictive and strictly needs-based.

- Mineral fertilizers are used only as needed and must consider variations within the fields (precision agriculture).

- Growing catch crops to prevent nitrogen leaching, grass plants in riparian buffer zones, and establishing wetlands to prevent particulate run-off and capture nitrogen are now subsidized through agri-payments.

- Financial support is now granted for the preservation of pasture land that is commonly a very species rich landscape.

Environmental management still needed

Still, there is much more to do, and several unresolved environmental issues remain that demand our full future attention. Here are examples.

Maintaining a satisfactory level of biodiversity and other biological values is a central task. Bird populations in farm landscapes have declined in recent decades. Grey partridge, corn bunting, and the common linnet are currently listed as threatened in Sweden.[21] The primary reason for this is the reduced availability of feed in winter, as more common planting of winter crops and fewer stub fields leave less seeds for these birds. As well, many insects and pollinators have declined in agricultural landscapes.[13,17,20]

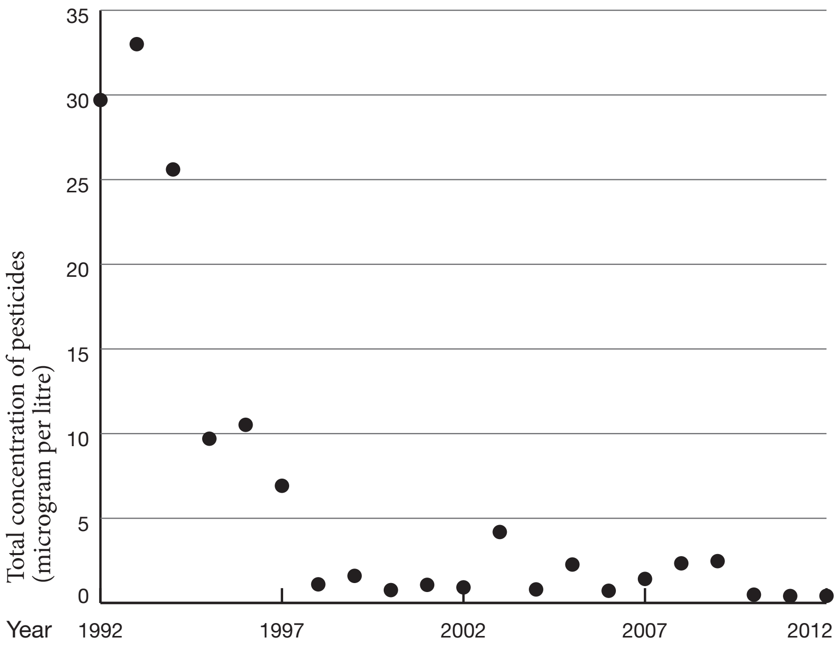


FIGURE 4. Mean concentration of pesticides (total levels) in surface water in Skåne has been reduced to 5 micrograms per litre.[14] This reduction is the result of stopping releases from point sources. This was made possible through regulations for handling, packaging, and refilling, and the cleaning of spray equipment at special locations (with bacterial beds) where the pesticides are broken down quickly without any leakage.

Several bumblebee species and solitary bees are listed as threatened.[21] This is due to the lack of flower rich environments (as with wild flowers growing on field edges), fewer natural pastures, and forage harvest for silage rather than hay. Silage is normally harvested earlier than hay, which reduces the availability of flowering host plants. Use of certain insecticides (neonicotinoids) have also likely contributed to negative trends. Therefore, another central task is to re-establish the prerequisites for a rich bird and insect life in agricultural landscapes.

Emissions of greenhouse gases from agriculture are unavoidable, but can and must be reduced. The most important greenhouse gases emitted are methane from ruminants, nitrous oxide from soil, and carbon dioxide from humus soils. The potential for achieving net reduction in greenhouse gases through carbon storage in farmlands is seen to be greater than for reducing methane and nitrous oxide departure.[3]

Phosphorus leaching must be reduced to the same extent as with nitrate nitrogen. Despite intensive efforts in recent years to develop appropriate and effective measures to reduce phosphorus leaching from farmland, these efforts have not fully succeeded yet.[1] This is partly due to the more complicated circulation of phosphorus in soil (as compared to nitrogen), making any corrective measure more complicated.

Reducing the hazards of using pesticides and thereby their prevalence in water and foodstuffs is currently a central environmental objective. The use of pesticides in agriculture has undergone huge changes in recent decades, which has steadily lowered levels of pesticide residues in surface and ground water (Figure 4).[14] The Swedish Chemicals Agency has set a high ambition level and used targeted efforts to phase out those pesticides having the greatest potential for causing harm. Yet, the fact that we can still find residues in our waters is unsatisfactory, requiring further effort. This identifies another important task – to further improve the handling and use of pesticides on individual farms, and reducing the number of point sources. Integrated plant protection, mandatory riparian buffer zones, new types of pesticides that have the greatest possible effect on the undesirable organisms and weeds while minimizing possible negative effects on human health and the environment are important issues. Altogether, a strict needs-based use with continued restrictive policies regarding pesticides can enable achieving the environmental quality objective of a 'Non-toxic environment'.

Literature Chapter 1

1) Bergström, L., Linder, A. & Andersson, R. (2008) *Fosforförluster från åkermark – vad kan vi göra för att minska problemet? (Phosphorus loss from farmland – what can we do to reduce the problem? Swedish only)* Jordbruksverket, Jordbruksinformation 27. Jönköping, Sweden, 26 p. http://www.greppa.nu/download/ 18.23f3563314184096e0d 2d26/1381489837476/Fosforf%C3%B6rluster+fr%C3%A5n+jordbruksm ark+Jordbruksinfo+27+2008+Jord bruksverket.pdf

2) Carson, R. (1962) *Silent Spring.* Houghton Mifflin Company, Boston, USA 400 p.

3) Dickie, A., Streck, C., Roe, S., Zurek, M., Haupt, F. & Dolginow, A. (2014) Strategies for mitigating climate change in agriculture: Recommendations for philanthropy – Executive Summary. Climate Focus and California Environmental Associates, prepared with the support of the Climate and Land Use Alliance. www.agriculturalmitigation.org.

4) Formas (2003) Är *eko reko? (Is Eco OK?) Om ekologiskt lantbruk i Sverige. (On Organic Farming in Sweden.* Formas Fokuserar, Stockholm, Sweden, 116 p.

5) Granstedt, A. (1985) *Naturresursbevarande jordbruk. (Natural resource preserving agriculture, Swedish only)* LT Förlag, Stockholm, Sweden, 136 p.

6) Jansson, S.L. (1962) *Odlingsmarkens bördighet, dess förändringar och bibehållande. (Fertility of farmlands, changes and maintenance) Svenskt skogs- och jordbruk 1913–1962 (Swedish Forestry and Agriculture 1913–1962, Swedish only)*. Minnesskrift från Kungliga Skogs- och Lantbruksakademien (KSLA), 97-122. (Publicatoin of the Royal Forestry and Agricultral Academy)

7) Jansson, S.L. (1964) Växtnäring och välfärdsutveckling (Plant nutrients and development of welfare, *Swedish only*). *Växtnäringsnytt*20, 5:1-9

8) Jansson, S.L. (1988) Hektarskördarnas utveckling inom svenskt jordbruk. (Trends in yield within Swedish agriculture, *Swedish only*). Kungliga Skogs- och Lantbruksakademiens Tidskrift 20, 77-92.Jansson, U. & Mårald, E. (2005) *Bruka, Odla, Hävda. Odlingssystem och Uthålligt Jordbruk under 400 år*. Kungliga Skogs- och Lantbruksakademien, Skogs- och lantbrukshistoriska meddelanden 33, Stockholm, Sverige, 323 s.

9) Jansson, U. & Mårald, E. (2005) *Bruka, Odla, Hävda. Odlingssystem och Uthålligt Jordbruk under 400 år. (Cultivation systems and Sustainable Farming for 400 years, Swedish only)* Kungliga Skogs- och Lantbruksakademien, Skogs- och lantbrukshistoriska meddelanden 33, Stockholm, Sweden, 323 p.

10) Johansson, G. & Gustafson, A. (2007) *Oberservationsfält på åkermark Avrinning och växtnäringsförluster för det agrohydrologiska året 2005/06 samt en långtidsöversikt (Observation fields on farmland Run-off and plant nutrient losses in the agrohydorlogical year 2005/2006, and long-term monitoring, Swedish only)* Swedish University of Agricultural Sciences, Department Aquatic Sciences and Assessment. Teknisk rapport 115 Technical report. Uppsala, Sweden, 38 p.

11) Jordbruksstatistisk Årsbok (2011) *Jordbruksstatistik med data om livsmed- el (Farming statistics with data on foodstuffs, Swedish only).* Statistic Sweden, SCB, Örebro, Sweden, 389 p. http://www.scb.se/Pages/ Publishing CalendarViewInfo 259923.aspx?PublObjId=15861

12) Koepf, H. (1973) Organic management reduces leaching of nitrate. *Biodynamics* 108, 20-30.

13) Krebs, J.R., Wilson, J.D., Bradbury, R.B. & Sirivardena, G.M. (1999) The second silent spring? *Nature* 400, 611-612.

14) Lindström, B., Larsson, M., Nanos, T. & Kreuger, J. (2013) Resultat från miljöövervakningen av bekämpningsmedel (växtskyddsmedel) (Results from environmental monitoring of pesticides (plant protection), Swedish only). Årssammanställning 2012 (Annual compilation). Swedish University of Agricultural Sciences, Department Aquatic Sciences and Assessment. Rapport 2013:14 (Report). Uppsala, Sweden, 82 p. http://www.slu.se/Documents/externwebben/centrumbildningar-projekt/ckb/Publikationer/M%c3%96%20Pesticider%20%c3%85rsrapport%202012.pdf

15) Mattson, R. (1985) *Jordbrukets utveckling i Sverige (The advance of agriculture in Sweden, Swedish only)*. News from the Agriculture University, no. 344. Uppsala, Sweden, 46 p.

16) Swedish EPA (2013) *Sveriges miljömål*. http://www.naturvardsverket.se/Miljoarbete-i-samhallet/Sveriges-miljomal/ (http://www.miljomal.se/sv/Environmental-Objectives-Portal/Undre-meny/About-the-Environmental-Objectives/)

17) Nilsson, S.G. & Franzén, M. (2009) Alarmerande minskning av dagfjärilar (The Alarming decline of butterflies, *Swedish only*). *Fauna och Flora* 104, 2-11.

18) Smil, V. (2001) *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production.* MIT Press, Cambridge, MA, USA, 338 p.

19) Stjernman Forsberg, L., Johansson, G. & Torstensson, G. (2013) *Växtnäringsförluster från åkermark 2011/2012 (Plant nutrient loss from farmland, Swedish only)*. Swedish University of Agricultural Sciences, Department Soil Sciences and Assessment. Ekohydrologi 136. Uppsala, Sweden, 20 p.

20) Svensson, B., Lagerlöf, J. & Svensson, B.G. (2000) Habitat preferences of nest-seeking bumble bees (Hymenoptera: Apidae) in an agricultural landscape. *Agriculture, Ecosystems and Environment* 77, 247-255.

21) Swedish University of Agricultural Sciences (2010) *Rödlistade arter i Sverige 2010 (Threatened species list for Sweden 2010, Swedish only)*. Gärdenfors, U. (red.) The Swedish Species Information Centre, Swedish University of Agricultural Sciences, Uppsala, Sweden, 545 p. http://www.slu.se/sv/centrumbildningar-och- projekt/artdatabanken/rodlistan/sammanfattande-resultat/

22) Sweden's National Atlas. (1992) *Jordbruket (Agriculture, Swedish only)*. Publisher Bra Böcker. Höganäs, Sweden, 128 p.

23) Sweden's National Atlas. (2011) *Jordbruk och skogsbruk i Sverige sedan* år *1900 (Agriculture and forestry in Sweden since 1900, Swedish only)*. Norstedts, Stockholm, Sweden, 232 p.

24) von Liebig, J. (1840) *Die organische Chemie in ihrer Anwendung auf Agrikultur und Physiologie*. Fr. Vieweg & Sohn, Braunschweig, Tyskland, 374 p.

2

The roots of organic farming

Organic farming has grown out of several popular movements, which were previously considered 'alternative' farming methods. The common denominator for these concepts is the exclusion of soluble mineral fertilizers and pesticides.[2,11] The 1980s saw the formation of an umbrella organisation for these alternative types of farming in Sweden under the name of KRAV[10] (the acronym for Control Organisation for Alternative Plant Farming, which conveniently spells the Swedish word for 'Requirements'). The term 'alternative farming' later became 'organic farming'. The timeline for the expansion of organic agriculture is illustrated in Figure 5.

Individuals credited with establishing alternative farming include the Austrian Rudolf Steiner (biodynamic farming), Lady Eve Balfour and Sir Albert Howard from Britain (organic farming), Hans-Peter Rusch from Germany, and Swiss Hans Müller (biological organic farming). Their rejection of mineral fertilizer and pesticides was a reaction to the industrialisation of agriculture, and their conviction that this degraded the quality of food.[5]

The word 'ecology' actually means the relationships of organisms to each other and their physical environment. In Sweden, alternative farming has taken the word ecology and used it as a synonym for environmentally-friendly agriculture. Now, many other products, such as clothes, furniture, and housing can be called 'ecological' or 'organic'.

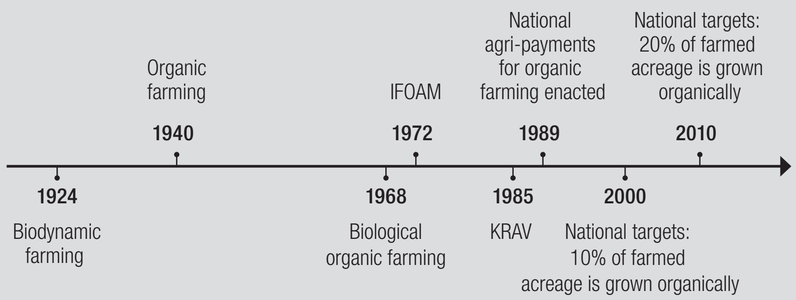


FIGURE 5. Timeline for the growth of organic farming in Sweden.

We provide here a brief description of these creators' views of nature and the methods that characterize the various types of organic farming. The primary ideas behind each of the organic growing methods differ (Table 2).

Biodynamic farming

The founder of biodynamic agriculture, the first form of organic farming,[13] was the Austrian philosopher Rudolf Steiner (1861–1925). He claimed that 'cosmic and terrestrial forces' have a central role in the production of sound foodstuffs. Steiner felt that mineral fertilizer disturbed these cosmic and terrestrial forces so that the quality of foodstuffs was degraded to the point it became unsuitable as sustenance. Steiner introduced biodynamic preparations that enabled control of these cosmic and terrestrial forces for the purpose of producing foodstuffs enriched by these forces.[7,8,9,13]

The quality of foodstuffs within biodynamic farming does not involve its contents – the proteins, vitamins, minerals and other known nutrients we think of today – but rather this involves the powers to be transferred to humans through their food. The production and use of eight preparations are based on Steiner's supernatural perception and provide the core for this type of agriculture. Two preparations are to be used on fields, while the others are used as ingredi-

TABLE 2. Origins and basic precepts behind organic farming methods.

Founder and Organisation	Philosophy and view of nature	Reasons why synthetic, fertilizer and pesticides are excluded	Writing
R STEINER (1861–1925) Biodynamic farming	Anthroposophy: 'Powers' in nature increase human spiritual consciousness.	Artificial substances disturb the flows of these 'powers' and destroy the 'spiritual' content of food.	*Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft* (1924)
A HOWARD (1873–1947) **E BALFOUR** (1899–1990) Organic farming	Nature Romanticism: Undisturbed nature means harmony. Humus guaranties the soil's fertility and assures health. Health is a birth right.	Humus is the most important of all natural resources. Mineral fertilizer increases the breakdown the stores of humus in soils.	*The Soil and Health* (1947) *The Living Soil* (1943)
H-P RUSCH (1906–1977) Biological organic farming	Eco philosophy: Nature is a perfect unit where every living thing has equal value.	Mineral fertilizer is not adapted to the needs of crops and results in poor quality. The occurrence of disease is the result of poor food quality.	*Bodenfruchtbarkeit - Eine Studie biologischen Denkens* (1968)
INTERNATIONAL FEDERATION OF ORGANIC AGRICULTURE MOVEMENTS (IFOAM) (1972)	Ecologism: Nature is a model and master.	Organic methods are superior to others and are therefore self-evident.	*The Principals of Organic Agriculture* (IFOAM, 2011)

ents for composting manure. Requirements for the composting of manure, forbidding the use of human waste, and annual application of preparations where primary ingredients in biodynamic farming. This biodynamic farming was a portion of Steiner's comprehensive philosophy known as Anthroposophy. The sciences find no substantiation or evidence for what these 'cosmic and terrestrial substitute with forces' are. Nor are there any scientific studies that confirm the active mechanisms and effect of these biodynamic preparations.

Organic (Natural) farming

Organic farming[1,3] was developed in England by Lady Eve Balfour (1899–1990) together with agronomist Sir Albert Howard (1873–1947). This type of agriculture centres on the humus content in the soil. The claim here is that high quality, healthy crops can only be produced in soils with high humus content. Preserving and increasing the humus content of the soil is a prerequisite to achieving fertile soils and sound foodstuffs. Humus was seen as a necessity for fully healthy plants, animals and people. But even humus-rich soil can lack important micronutrients, such as copper. The use of mineral fertilizer is questioned because it is seen to accelerate the breakdown of existing humus, which thereby deteriorates the soil's fertility. Composting organic waste from urban areas was seen as necessary to increase humus stores in the soil.

The preconception that mineral fertilizer reduces the amount of humus in the soil – and thereby its fertility – has been shown to be incorrect.[6] Humus in the soil breaks down no faster with the application of nitrogen fertilizer. Instead, mineral fertilizer increases the production of plant biomass, including more roots. And, since roots and crop residues provide the raw material in the formation of humus, mineral fertilizer has been shown to increase the amount of humus in the soil as compared to organically farmed soils. The possibility of adding extra humus to soils from the sorted organic waste from urban areas, for example, has been shown to provide a very limited addition of humus. The volumes are simply too small to be able to raise the amount of humus in farm fields.

Biological organic farming

The originators behind biological organic farming[12] are the German physician, Hans Peter Rusch (1906–1977), and Swiss agricultural politician, Dr Hans Müller (1891–1988). According to this type of farming, the choice of agriculture methods is based on natural processes. This means that farmers in their practice imitate these cycles. Soil should not be ploughed, only worked from the surface, since ploughing does not occur naturally. Further, organic material should not be composted, but rather added fresh as soil cover to compost on the surface. Degradation of minerals should be mimicked by applying stone dust as the source of plant nutrients. The formation of humus is seen as nature's most important function and an expression of biological performance. Mineral fertilizer is seen as the basic reason for disease in crops, which cause disease in animals and humans. Without mineral fertilizer, the crops would remain healthy, and no pesticides would be needed.

Many of these methods have been shown to not work in practice. Soil preparation without ploughing, or no-till farming, cannot be applied to every soil type. The benefits of applying either compost or fresh organic material to soil depends on the type of organic material involved, the possible spread of diseases with the material, and local soil and climate conditions. The claimed relationship between mineral fertilizer and plant diseases has never been established after years of research.

> ***The foundation of organic farming is based on its founders' criticism of the use of mineral fertilizer. This critical view against mineral fertilizer originates in the founders' views of nature, and is not supported by scientifically based understanding. Today's organic farming excludes mineral fertilizer and chemical pesticides, which essentially follows these historical predecessors in this regard.***

Today's organic farming

Current proponents of organic farming often do reject the teachings we describe above. Still, this type of farming is based on the idea that synthetic fertilizers and pesticides should not be used in agriculture since they are not natural. The objective is to promote a natural and sound food production that is free from toxins, and which preserves the fertility of the soil. That this will improve the environment is seen as a self-evident consequence.

Other than the initial emphasis on achieving high soil fertility and healthy food, ideas within organic farming have been supplemented with newer objectives such as husbandry of resources, greater energy efficiency, reduced climate impact, and biodiversity. Special rules have also been established for organic animal keeping, but we will not discuss these in this book.

The various teachings of organic production are combined in the common principles developed by the International Federation of Organic Agricultural Movements (IFOAM).[4] These include health, ecology, fairness, and care. The organisation in Sweden that formulates the regulatory framework for organic certification is KRAV – which is more a commercial business than a control body. Additionally, there are also types of organic farming that do receive governmental agri-environmental payments, but which are not KRAV certified, and there is EU certified organic production.

Literature Chapter 2

1) Balfour, E.A. (1943) *The Living Soil*. Faber & Faber Ltd. London, England, 276 p.

2) Conford, P. (2001) *The Origins of the Organic Movement.* Floris Books, Edinburgh, England, 237 p.

3) Howard, A. (1943) *An Agricultural Testament*, Oxford University Press, Oxford, England, 253 p..

4) IFOAM. (2011) *The Principles of Organic Agriculture*. The International Federation of Organic Agriculture Movements. www.IFOAM.org, Bonn.

5) Jansson, S.L. (1948) Reformtendenser inom jordbruket (Reform tendencies in Agriculture, Swedish only). *Kungliga Skogs- och Lantbruksakademiens Tidskrift* 87, 129-160.

6) Jansson, S.L. (1958) Tracer studies on nitrogen transformations in soil with special attention to mineralization-immobilization relationships. *Annuals of the Royal Agricultural College of Sweden* 24, 101-361.

7) Kirchmann, H. (1994) Biological dynamic farming – an occult form of alternative agriculture? *Journal of Agricultural and Environmental Ethics* 7(2), 173-187.

8) Kirchmann, H. & Andrén, O. (2003) Biodynamiskt och ekologiskt lantbruk (Biodynamik and organic farming). I Jerkert, J. (red.) *Antroposofin – En kritisk granskning (Anthropomorphic - a critical review, Swedish only)*. Edita AB Tryck, Stockholm, Sweden, p. 54-70.

9) Kirchmann, H., Thorvaldsson, G., Bergström, L., Gerzabek, M., Andrén, O., Eriksson, L-O. & Winninge, M. (2008) "Fundamentals of organic agriculture – past and present." I Kirchmann, H. & Bergström L. (red.) Organic Crop Production – Ambitions and Limitations. Springer, Dordrecht, Nederländerna, p. 12-38. http://pub-epsilon.slu.se/509/

10) KRAV rules (2011) www.krav.se/Kravsregler.

11) Merrill, M.C. (1983) Eco-Agriculture: A review of its history and philosophy. *Biological Agriculture and Horticulture* 1, 181-210.

12) Rusch, H.P. (1978) *Bodenfruchtbarkeit. Eine Studie biologischen Denkens (German only)*, 3. Auflage. Haug Verlag, Heidelberg, Tyskland, 243 p.

13) Steiner, R. (1924) *Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft (Spiritual Foundations for the Renewal of Agriculture, (German only).* Rudolf Steiner Nachlassverwaltung, 5. Auflage 1975, Dornach, Tyskland, 256 p.

3

Will we have enough food after converting to organic farming?

Forecasts indicate the population of the earth will increase from today's over 7 billion to as much as 9.15 billion by 2050.[11] Moreover, the increase in food production necessary for this is estimated to be approximately 60 - 70 per cent.[11] But the world is experiencing a food shortage even today. Currently, nearly 1 billion people do not have adequate food supplies to fully meet their nutritional needs.[13,26] Therefore, the greater challenge for agriculture is to produce even more food for the needs of future generations.

Would there be enough food after large scale conversion to organic production?[6, 7, 16, 20] Can organic production meet future food supply demands with this forecasted population growth? This chapter addresses the effects of organic farming on the food supply.

The food supply in Sweden

Total farmed acreage in Sweden reached its peak in the 1930s when approximately 3.5 million hectares of land were used for food production. Since then, fields with lowest yield are used only for permanent grazing, and the poorest land has been planted with forest. This led to a decrease in total farmed acreage to approximately 3 million hectares by 1990, and this has since decreased further to some 2.6 million hectares.

TABLE 3. Yield increase in conventional farming in Sweden from 1982–2010. The data are based on official Swedish statistics.[18]

Crops	Average yield 1982–1990 (kg per hectare)	Average yield 2000-2010 (kg per hectare)	Yield increase over 20 years (%)	Yield increase annually (%)
Winter wheat	5500	6200	11	0.55
Barley	3600	4200	14	0.70
Oats	3600	3900	7	0.35

Dividing the total farmed acreage in Sweden (2.6 million hectares) by current population (close to 10 million), there are approximately 0.26 hectares' arable land per person, which is too little for our diet of largely animal products when this acreage can only be utilized half the year. Currently, Sweden's self-sufficiency rate is less than 50 per cent, showing that a large proportion of the country's food requirements must be imported.

This dependency on imports to meet food needs arose after 1989 when the country abandoned its formal policy of self-sufficiency. As examples, Sweden imports beef from Ireland and South America, and pork from Denmark, which were previously produced domestically. Globally, agricultural production is increasing by approximately 1 per cent annually, while yearly demand for foodstuffs is increasing by nearly 2 per cent.[11]

Crop production in Sweden has increased only some 0.5 per cent annually (Table 3), while nearly 1 million hectares of arable land is no longer farmed for food, but rather is used for forestry, energy crops, grazing, and similar. As the farmed acreage in Sweden has declined, the country's need to import food has risen. Higher yields have not compensated for the increase in food requirements. More broadly, arable land is a limited resource across the globe, where generally all suitable land for farming is being used. Globally therefore, there is 0.23 hectare's arable land per person.

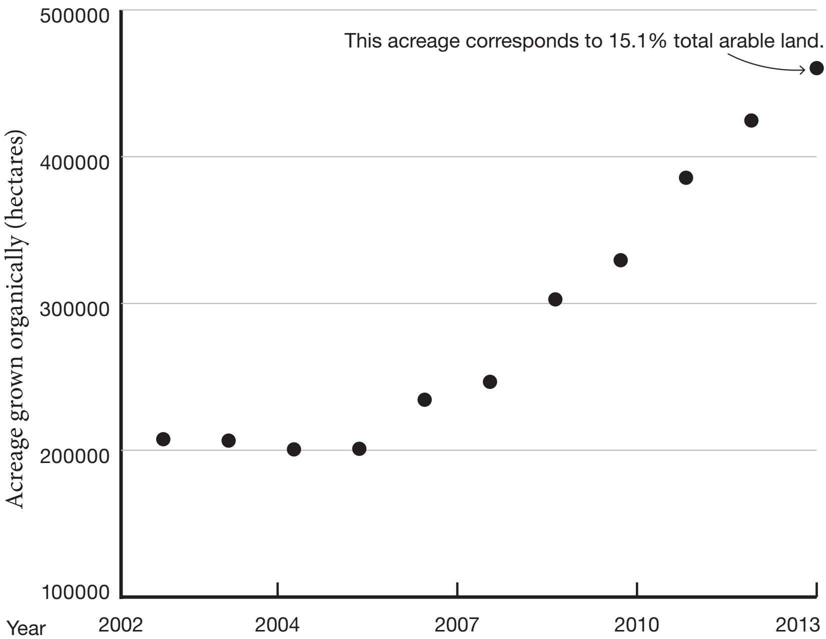


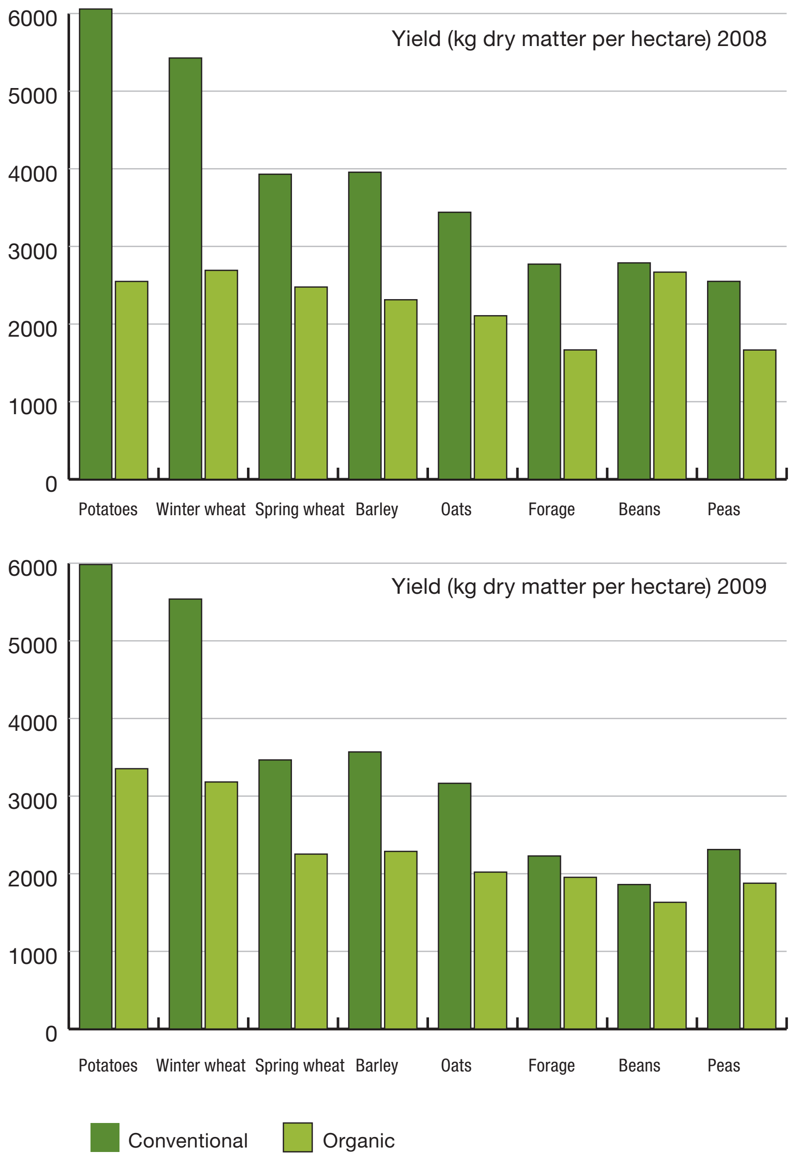
FIGURE 6. The change in Swedish acreage farmed organically. The data are based on official Swedish statistics.[18]

Throughout the last decades of the 1900s, the western world experienced importune surpluses in food production. In Europe, this was criticized as 'meat' and 'butter' mountains. Sweden led the way in addressing this problem with a series of policies, whereby government paid farmers to put land in fallow, cut agricultural subsidies, and set a target for 20 per cent of farmed land to be organic (Figure 6). Today's situation is entirely different. The surpluses are gone, cereals (a portion of annual production) are used to produce bio-fuels (ethanol) and the consumption of meat and other animal products has increased, in Sweden as in the rest of the world, not least in China. Once again, producing enough food for national consumption without adding to environmental loads has become an important issue. But there is no policy goal in Sweden in favour of something as fundamental as self-sufficiency in food production.Importing even more foodstuffs to Sweden is also questionable considering the continuing growth in demand elsewhere in the world. As well, the prerequisites for more environmentally friendly food production are in many ways better in Sweden than in many other countries. Preserving farmland for domestic food production should be an important goal for society. Indeed, it is as important to society, as converting to renewable energy, preserving biodiversity, eliminating eutrophication of natural waters, reducing climate impact, and much more.

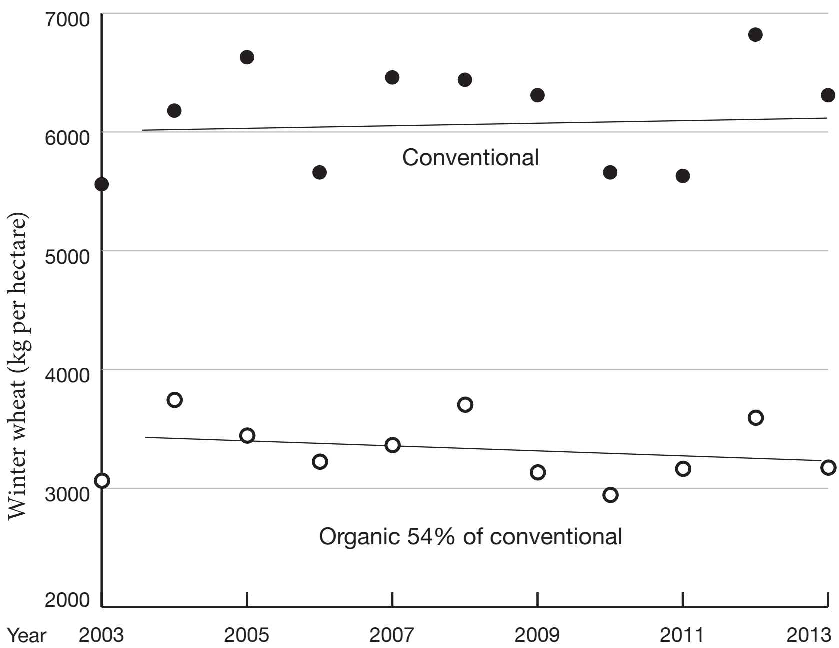
Yield size from organic farming

How large are yields from organic farming in Sweden? Official Swedish yield statistics show that organic farming practices produce significantly lower yields than conventional farming. Swedish Board of Agriculture data show that yields are on average approximately 40 per cent reduced after conversion to organic production (Figure 7).[18] But for potatoes, for example, this reduction is even greater since this crop is especially vulnerable to fungal infection and pests. Some years the entire crop may be lost. Moreover, the official statistics overestimate organic yields. These statistics do not include years when green manure is ploughed back into the soil (with no harvest). This also fails to include growing seasons missed when fields are put in fallow to control perennial weeds – which cannot be otherwise controlled in organic farming.

Lost growing seasons give zero yield, and should be included in calculating the long-term supply capability of organic farming. The actual reduction in yield with organic farming is closer to 50 per cent compared to conventional farming methods. And yet, the acreage that is organically farmed is increasing significantly (Figure 6). Some data does find that yields can be as large or larger with organic farming.[9,22] But a closer look at these organic farms shows their high yields always depend on the extensive import of plant nutrients in the form of purchased organic fertilizers,



FIGUR 7. Official yield statistics from Statistics Sweden[18] show that organic farming reduces yields by approximately 40 percent (the volume of forage refers to the first harvest).



FIGUR 8. Yield trends for winter wheat for the last ten years. The data are based on official Swedish statistics.[18]

including manure and straw from conventional farms, and meat and bone meal from the food industry (as detailed in chapter 5). In total, yields are much lower for organic as opposed to conventional farming.

A common preconception is that yields from organic farms can also be increased long-term through further development and improvement of organic cultivation systems. Directed national research funding for improving organic farming has promoted this since the 1980s. Still, Swedish yield statistics show that no increase has occurred for organic farming (see the example of winter wheat in Figure 8.[18] Findings from long-term field trails in Sweden, comparing organic to conventional farming over decades, show yields remaining lower for organic farms.[7,21] The same laws of nature and growing conditions apply to both organic and conventional farming methods. Pests must still be controlled, weeds held back, and crops and soil must be fertilized to achieve good yields while preserving soil fertility. To improve yields with organic farming practice would require improvement in a range of practices, including: that mechanical weed control becomes a viable alternative, biological pest control becomes effective at full-scale, nutrient release from organic fertilizer and untreated minerals occurs when needed by crops so sufficient plant nutrients reach the crops.

Food supply with large-scale organic production

Only recently has it become generally understood that yields in organic farming are significantly lower. This means that if organic farming becomes even more dominant and less acreage is grown conventionally, there will simply not be enough food produced.[6,7,16] When discussing food supply, advocates of organic farming claim that food supplies would be sufficient if we change our diets to be more vegetarian. This claims a primarily vegetarian diet would free farmland currently used to produce animal feed to use in growing crops for human consumption. Suggesting that a narrower range of foodstuffs can be addressed by shifting to largely vegetarian foods sounds like a positive solution. But this may also be an after-thought to minimize the spectre of food shortages – and, in the end, starvation – resulting from large scale organic farming. In any case, such a proposal is certainly not based on freedom of choice, and ignores the simple fact that conventional farming would still clearly be the most efficient form of production, even for a vegetarian diet. Then, crop land could be freed for other types of production, such as for biofuels. Growing crops for human consumption is not only less demanding in terms of acreage, but is also less demanding on resources and has environmental benefits as compared to animal production. But, there is a catch. Which is, that keeping animals is

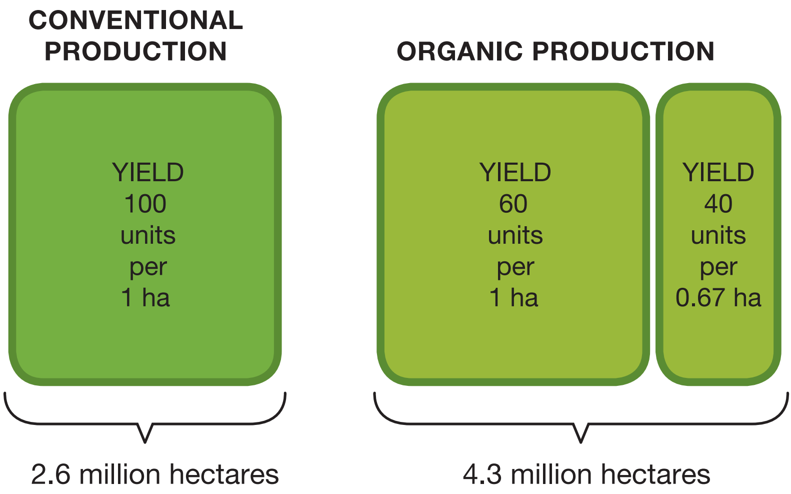


FIGURE 9. A yield reduction of approximately 40 per cent with organic farming as compared to conventional production, would require farmed acreage be increased by 67 per cent for full-scale conversion to organic farming in order to produce the same amount of food given current dietary habits.

more or less necessary for organic farming since the farm animals, especially cattle that convert plant roughage to food products, are an integrated part of any organic farming system, and grassland product is an important component in organic crop rotation. In other words, it is very difficult to combine a vegetarian selection of foods with organic production.

Without a change in diet, large scale organic farming would require much greater farmed acreage than the 2.6 million hectares of land currently in production, just to compensate for the yield reduction. In Sweden, this would require 4.3 million hectares farmed land, equalling a 70 per cent increase in the total. This is the total necessary to organically produce all foodstuffs currently consumed in Sweden (Figure 9). But Sweden has never had that much land in production.

Every available type of land would have to be put under the plough, necessitating drastic measures. This would mean putting not only all abandoned farmland back into production, it would also involve ploughing down large tracts of forest lands and untouched wilderness. The consequences of such a huge change in land use are difficult to predict. Most likely, this would involve appreciable loss in forestry and bioenergy production, increased loads on water resources, greater emissions of greenhouse gases, and unpredictable effects on biodiversity. In short, considering the wider perspective, large scale organic farming to meet all food requirements appears to be a scenario without any environmental benefits.

A last resort to address any food shortages caused by such a scenario in Sweden is naturally to compensate lost production with imported food. But that choice would mean more than simply taking food from countries where it may also be needed, it would also involve 'exporting' the very same environmental issues caused by farming. It is also important to consider that the conditions for farming in Sweden are very favourable. The country has fertile land and good climate conditions for farming many types of crops. So much of the food needed in the country could easily be produced.

Organic farming leads to significantly lower yields. The food supply cannot be secured with large-scale organic production with the same type of diet.

Dietary composition with large-scale organic production

Large-scale organic farming will not only impact the amount of food produced, but will also affect the types of food available. Crop rotation will, in the end, affect the types of food offered on the market. Does the organic farmer grow the same crops as the conventional farmer, and if not, which crops are primarily grown in organic farming?

TABLE 4. Relative distribution of crops in organic and conventional plant production. The data are based on official Swedish statistics.[18]

Crops	Use of farm land for various crops (%)		Change for organic farming (%)	
	Conventional	Organic	Acreage	Type of crop*
Forage	49	69	+ 41	+ 31
Legumes	1.2	2.3	+ 92	+ 83
Cereals	43	27	- 38	- 73
Oilseed plants	3.8	1.0	- 74	- 84
Potatoes	1.2	0.3	- 75	- 87
Other	1.8	0.4	- 78	-

* Lower yields for organic farming have been considered

Official Swedish statistics show that the share of forage, peas, and beans is significantly greater in organic cultivation systems (Table 4).[18] The acreage dedicated to legumes increases by over 90 percent and the acreage of forage by 40 per cent in organic farming. This increase comes at the price of cereals, which become approximately 40 per cent less compared to conventional production. The reason for this drastic change is that legumes (clover in forage, peas and beans) must be chosen to a greater extent in organic farming since these plants fix nitrogen from the air into soil, whereby this nitrogen is provided to the other crops.

As well, the differences in yields are relatively small compared to conventionally farmed legumes (see Figure 7, page 39). Since growing legumes is promoted in organic systems, more forage for cattle is also grown. The forage is needed to add nitrogen to the system, eliminate weeds, and produce manure. The manure enables recirculating a portion of the plant nutrients back to crop fields and contributes to nitrogen supply for non-nitrogen fixing crops. Growing more forage and less cereals, in turn, impacts the type of animal keeping necessary. More forage means a greater share of cattle, sheep, and horses, and lower production of cereals means less feed available for keeping pigs and poultry (whose feed is primarily cereal products). The size of the increase in cattle and sheep is difficult to predict, but the amount of pork and poultry available in full-scale organic, as compared to conventional, farming would obviously decrease significantly.

The greatest change when converting to organic production is the 75 per cent reduction in acreage devoted to crops like potatoes and oil seeds (Table 4). Potatoes and rapeseed are especially sensitive to fungal infection and insect infestation, respectively, which are difficult to control using organic methods. If full-scale organic farming were used in Sweden with modern crop rotation, potatoes and oilseed production would be only 12.5 and 16 per cent, respectively, of current levels – counting both the lower yields and reduction is planted acreage. Cereal production would similarly decline to approximately 38 per cent of current levels, while forage production would increase 30 to 35 per cent.

A conversion to full-scale organic farming on existing farmlands in Sweden would drastically change the range of foodstuffs available due to lower yields and the different crops grown.[19] Lost production would need to be compensated with imports, but the average diet would also be affected. This diet would likely be dominated by more cereals and legumes, while the arch typical Swedish potato, and rapeseed products would be in short supply. Beef and dairy products would become totally dominant in animal production.

A global perspective – sufficient food for a growing population

Undeniably, a massive increase in food production and a comprehensive perspective on future food supply is needed[14] to meet the needs of a growing population. That's why there are so many books predicting future food shortages, such as *The coming famine* by Julian Cribb[8], while voices in Sweden have also been raised in recent years including MEP Marit Paulsen. Farmland is, indeed, a finite resource. The total arable land on the Earth is approximately 1.4 billion hectares,[12] of which only some 1 billion hectares are suitable for crop production. The other 400 million hectares of farmland includes generally less productive areas in regions that are either too hot, dry, or cold, or too steep and rocky.[10] Moreover the amount of farmed acreage is decreasing due to soil erosion along slopes, wind erosion in desert areas, salinification from over irrigation, and not least by urbanisation of farmland. Therefore, discussing the concept of 'peak soil' is at least as important as considering 'peak phosphorus' and 'peak oil.'

Since the availability of farmland on our earth is limited, that limited acreage must support any increase in production. The alternative is to convert large tracts of forest or natural lands to add farmland. But this is generally a less attractive idea due to the impact this would have on biodiversity (linked to wilderness), the loss of ecosystem services, and the added environmental load. As well, there is strong reason to believe that the largest portion of any increase in food production must occur in developing countries.[11]

Agricultural production is low in many countries and is in general significantly lower than in the developed world. In many cases yield levels are only a fraction of what we see in developed countries. This is largely due to soil depletion[23] and lack of funding, which prevents the purchase of sufficient amounts of fertilizer (including its general unavailability). Worth noting is the conclusion of UN General Secretary Ban Ki-Moon speaking at the FAO meeting in Rome in 2008: that one of the most important ways to address famine in developing countries is to increase the use of mineral fertilizer. Access to water can, however, also substantially limit the ability to achieve higher yields.

Which cultivation system will then enable a sufficient increase in yields? Can organic production provide a realistic means to substantially increase yields in developing countries? Media reports sometimes indicate that organic production was used to multiply yields in developing countries.

Organic farming is presented in these cases as a way to improve these countries' future agriculture. But these reports provide a narrow view of what agriculture research has been able to show, as in Africa for example. The key to achieving higher yields in Africa, is to improve soil fertility and increase the supply of nutrients to crops.[24]

In other words, depleted stores of soil nutrients must be replenished, the crops must be able to access more nutrients, and the water retention capabilities and humus content of soils must be increased.[2,4] Many measures are needed to accomplish this, but most of all organic and mineral fertilizer is needed,[23,25] as we explain below.

The claim that using only existing and natural nutrient resources – resources that have always existed now as before – could be the path towards doubling production must be corrected.[24] In trials it is easy to show how to raise yields several hundred percent by applying organic fertilizer.[1] Maize yields in developing countries can, for example be raised from 500 to 2,000 kilo per hectare – which is a huge increase. But this higher figure still only represents a low yield.

These results are achieved by adding large amounts of organic fertilizer (such as manure, compost, green biomass, leaves, termite soil) on a smaller crop field. The manure is obtained from farm animals (most often cattle) and other organic material is taken from nearby. Larger yields can be obtained as long as large volumes of nutrient rich organic material are applied to these fields. But, there is no evidence that these higher yields can be achieved on a wider scale.

The bottleneck here is the amount of and access to organic fertilizer – which is quite limited. Nutrient rich organic material suitable for fertilizer is a finite resource in practice.[5] There is simply not enough manure, compost, and nutrient rich green fertilizer around. This therefore shows that the trials reported are not valid for a full-scale reality.

We emphasize here that the reallocation of plant nutrients from natural lands to farm fields cannot change the long-term nutrient depletion of soils that has always occurred through the centuries. We see that the extensive slash and burn farming in many less-developed countries, as with the early grassland farming in Sweden, has not been able to counter-act the depletion of soils. Thereby, improved yields over the long-term cannot be maintained, as we discussed in Chapter 1.

Increasing yields in third-world countries firstly requires better understanding of how to run resource-efficient farming on depleted lands utilizing local resources, but supplemented with mineral fertilizer.[2,9,15] These farmers can be helped by selling small amounts of mineral fertilizer to them to slowly increase their yields, and thereby secure food supply. This also helps them create the conditions for earning income by selling part of their harvested products. Such a strategy has already been shown successful when tried in several African countries. In drier areas, building more dams would help to store more water with currently available technical solutions to limit evaporation, and thereby support higher food production. Farming in these countries should be based on existing agricultural methods that are developed from local experience.

The fact is that many small farmers in developing countries have, chiefly only for economic reasons, never used mineral fertilizer or pesticides. But many have experienced lost harvests, food shortage, and poverty. Interest for 'organic farming' among these small farmers, their farming associations, and political representatives is often limited. Many have difficulty believing that organic farming based on the same principles they already use, without mineral fertilizer and plant protection agents, would be able to provide higher yields and greater food security. We find it dubious to promote organic farming in countries where food shortages exist since this counteracts efforts for secure and sufficient food production.

Producing enough high quality food is one of the absolutely most important tasks in a society, and a cornerstone for prosperity.[3] Insufficient food supplies leads to the cessation of many vital society functions. Lack of food is probably the single most important cause of large-scale conflicts between peoples and nations. When life itself is threatened by the lack of food, every possible means, including violence, is used to survive. The 1949 Nobel Peace Prize Laureate Lord John Boyd Orr (1880–1971) described this with his famous words: "You can't build peace on empty stomachs." In this context, these are thoughtful words to consider.

Farmland is, indeed, a finite resource. Only greater production on existing farmland can guarantee future food requirements.

Literature Chapter 3

1) Bationo, A. (2007) Lessons learnt from long-term experiments in Africa. *Kungliga Skogs- och Lantbruksakademiens Tidskrift* 146, 30-35.

2) Bergström, L. & Kirchmann, H. (1998) *Carbon and Nutrient Cycling in Natural and Agricultural Tropical Ecosystems*. CAB International, Wallingford, England, 319 p.

3) Borlaug, N.E. (1970) *The Green Revolution, Peace and Humanity* – Nobel lecture, December 11, 1970, www.agbioworld.org/biotech-info/topics/borlaug/nobel-speech.html, Agbioworld, Tuskegee Institute, AL 36087-0085, USA.

4) Buresh, R., Sanchez, P.A. & Calhoun, F. (1997) *Replenishing Soil Fertility in Africa.* Soil Science Society of America, Special Publication 51. Madison, Wisconsin, USA, 251 p.

5) Campbell, B., Frost, P., Kirchmann, H. & Swift, M. (1998) A survey of soil fertility management in small-scale farming systems in North Eastern Zimbabwe. *Journal of Sustainable Agriculture* 11, 19-39.

6) Chen, F. & Wan, K. (2005) The impact of organic agriculture on food quantity, food quality and the environment: a Chinese perspective. *Soil Use and Management* 21, 73-74.

7) Connor, D.J. (2008) Organic agriculture cannot feed the world. *Field Crops Research* 106, 187-190.

8) Cribb, J. (2010) *The Coming Famine: The Global Food Crisis and What We Can Do to Avoid It.* University of California Press, Berkeley, Los Angeles, USA, 248 p.

9) De Schutter, O. (2010) *Agroecology and the right to food.* Report presented at the 16th Session of the United Nations Human Rights Council [A/HRC/16/49], 8 March 2011. http://www.srfood.org/images/stories/pdf/official reports/20110308_a-hrc-16-49_agroecology_en.pdf

10) Eswaran, H., Beinroth, F. & Reich, P. (1999) Global land resources and population-supporting capacity. *American Journal of Alternative Agriculture* 14, 129-136.

11) FAO. (2012) *World Agriculture Towards 2030/2050.* 2012 Revision. http://www.fao.org/docrep/016/ap106e/ap106e.pdf

12) FAO. (2012) *Statistical Yearbook*. http://www.fao.org/docrep/015/i2490e/i2490e00.htm

13) FAO. (2012) *The State of Food Insecurity in the World 2012*. http://www.fao.org/docrep/016/i3027e/i3027e00.htm

14) Foley, J.A., Ramankutty, N., Brauman, K.A.,Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, p., Tilman, D. & Zaks, D. P. M. (2011) Solutions for a cultivated planet. *Nature* 478, 337-342.

15) Giller, K.E., Witter, E., Corbeels, M. & Tittonell, P. (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* 114, 23-34.

16) Goulding, K.W.T., Trewavas, A.J. & Giller, K. (2009) *Can organic farming feed the world? A contribution to the debate on the ability of organic farming systems to provide sustainable supplies of food*. International Fertilizer Society Proceedings 663.York, U.K.

17) Ivarson, J. & Gunnarsson, A. (2001) *Försök med konventionella och ekologiska odlingsformer* 1987–1998 *(Trials with conventional and organic farming. Swedish only)*. Swedish University of Agricultural Sciences, Meddelande från södra jordbruksförsöksdistriktet (Notification from the southern farm district No. 53, Alnarp, Sweden, 165 p.

18) Jordbruksstatistisk Årsbok (2011) *Jordbruksstatistik med data om livsmed- el (Farming statistics with data on foodstuffs, Swedish only)*. Statistic Sweden, SCB, Örebro, Sweden, 389 p. http://www.scb. se/Pages/PublishingCalendarViewInfo 259923.aspx?PublObjId=15861.

19) Kirchmann, H. & Bergström, L. (2012) Human health issues associated with nutrient use in organic and conventional crop production. I Bruulsema, T.W. et al. (red.) *Fertilizing Crops to Improve Human Health: a Scientific Review.* International Plant Nutrition Institute, Norcross, GA, USA, p. 241-273.

20) Kirchmann, H., Bergström, L., Kätterer, T., Andrén, O. & Andersson, R. (2008) Can organic crop production feed the world? I Kirchmann, H. & Bergström L. (red.) *Organic Crop Production – Ambitions and Limitations,* Springer, Dordrecht, Nederländerna, p. 39-72. http://pub-epsilon.slu.se/514/

21) Kirchmann, H., Bergström, L., Kätterer, T., Mattsson, L. & Gesslein, S. (2007) Comparison of long-term organic and conventional crop-livestock systems in a previously nutrient-depleted soil in Sweden. *Agronomy Journal* 99, 960-972.

22) Seufert, V., Ramankutty, N. & Foley, A.E. (2012) Comparing the yields of organic and conventional agriculture. *Nature* 485, 229-232.

23) Sanchez, P.A. (2002) Soil fertility and hunger in Africa. *Science* 295, 2019-2020.

24) Vanlauwe, B. & Giller, K.E. (2006) Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture Ecosystems and Environment* 116, 34-46.

25) Vanlauwe, B., Wendt, J. & Diels, J. (2001) Combined application of organic matter and fertilizer. I Tian, G. et al. (red.) *Sustaining Soil Fertility in West-Africa*. Soil Science Society of America, Special Publication 58. Madison, Wisconsin, USA, p. 247-280.

26) World Hunger (2013) World hunger and poverty facts, statistics. http://www.worldhunger.org/articles/Learn/world%20hunger%20facts%20 2002.htm

4

Is organic food healthier?

Many people buy organic food in the conviction that these products are more wholesome than conventionally produced products. Thinking, for example, that these products contain more of healthier substances (like vitamins, minerals, and antioxidants). Many also practice organic farming because they feel it is good for the environment and contributes to better animal care. The most important difference between organic and conventional production is that mineral fertilizer is used only in conventional systems. In regard to plant protection, conventional farming also primarily uses synthetic agents, while organic farming uses natural agents. The question to ask is: Can the differences in inputs give rise to different quality? This basic question is the subject of our chapter here.

The founders of organic farming claimed from the beginning that it produces superior quality foodstuffs.[4,28,30] And this preconception remains among advocates and representative organizations who promote organic agriculture. These all claim that our food can only have high levels of minerals, vitamins, and other nutritious substances, and be free from toxins through the exclusion of mineral fertilizer and pesticides in farming practice.[5,12] Comparative studies designed to determine differences in quality between organically and conventionally grown products have been conducted since the start of organic farming in the 1920s. We will discuss the important findings here.

TABLE 5. Statistically confirmed differences in the properties of organically and conventionally grown crops [5,7,9,29,31,33] and the reasons for these differences.

Quality differences	Cause
Higher nitrate content in conventionally farmed vegetables	More plant available nitrogen in the ground
Higher protein content in conventionally farmed cereals	More plant available nitrogen in the ground
Higher levels of dry substances in organic crops	Smaller size of cells in organic crops means less water per cell
Higher vitamin C levels in organic vegetables	More light penetration to each leaf and less shading due to thinner plant stands in organic farming
Higher phosphate levels in organic vegetables	Cause not determined. One reason may be less shading in organic plant stands

Protein and nitrate content

Nitrogen is the most important plant nutrient in relation to yield. Fertilizing with nitrogen stimulates growth and affects the composition of crops more than any other plant nutrient. An initial significant production of biomass is followed by increased formation of green plant parts, that contain more chlorophyll. Nitrogen fertilization increases the levels of proteins[23] and fats, while stimulating vitamin synthesis.[26]

Several broad reviews of current research have found that protein and nitrate levels are lower in organic than conventional crops (Table 5).[5,7,9,29] Proponents of organic farming hold that the lower protein and nitrate levels in these crops indicates better quality. Their argument accepts the lower levels of protein, but claims the quality of these proteins' is more wholesome. Lower nitrate levels are said to be better, based on the preconception that nitrates are harmful to human health.[5]

The content of proteins, nitrates, and nitrogen in crops depends on nitrogen supply to the crop. Conventional farming practice tries to supply nitrogen to meet the needs of the crop, which results in higher levels of nitrogen and proteins in the plant, and sometimes also nitrates. Proteins consist of amino acids. Ten amino acids are essential, because they cannot be produced in the human body, and must therefore be obtained through our food. Studies of protein quality have shown that the share of essential amino acids is no different in organic or conventional crops.[13] Today, wheat is fertilized in the summer to raise levels of gluten protein, which improves baking properties. For oats, late nitrogen application generally provides higher protein content. Since there are no significant differences in the composition of amino acids between conventional and organic cereals, except for the addition of gluten, the lower levels of protein simply provide no advantage. Higher protein levels provide greater nutritional value.

Nitrates were previously classified as an undesirable substance in food, as it was thought to cause cancer in the digestive tract by forming toxic nitrosamines. That is why many writers have claimed that high nitrate levels in our food are harmful.[5] But in 1994, it was found that the human body produces its own nitrates.[10] Nitrate is introduced through saliva and is transformed in the oral cavity to nitrite. This nitrite is ingested to the stomach and reacts with natural hydrochloric acid to form nitrogen oxides. This combination of nitrogen oxides and hydrochloric acid in the stomach is an effective bactericide. This nitrate-nitrite-nitric oxide mechanism has been found to play an important role in the human immune system.[22,23] And, no more gastro-intestinal cancer cases were found in populations with high intake of nitrates.[20] Rather, it was found that the high nitrate intake has positive health effects.[23]

Nitrates are found in significant amounts in our diet, mostly in vegetables. The levels of these in vegetables varies between 1 mg per kilogram (peas) up to 4,800 mg per kilogram (ruccola). The European Food Safety Authority (EFSA)[11] wrote that "Overall, the estimated exposures to nitrate from vegetables are unlikely to result in appreciable health risks, therefore the recognised beneficial effects from the consumption of vegetables prevail." The preconception that nitrates are a toxic substance was thereby discredited. Late in the 1990s, views on nitrates in food were therefore revised, and they are now seen as beneficial for adults.[27]

To conclude, we can state that neither low levels of proteins or nitrate levels in organic crops can be considered an indication of better quality, but rather that higher levels of these in crops provides better quality.

Vitamin A

An adequate supply of nitrogen in crops stimulates the synthesis of proteins. This means greater formation of green plant parts containing chlorophyll, and also carotenes, which means higher levels of vitamin A.[26] β-carotene (beta-carotene) is the base substance for vitamin A. Carotenes are integrated with chlorophyll in the leaves (in the reaction centres for light absorption) and work to capture light from the more high-energy solar radiation. Carotenes are fat-soluble yellow, orange, or red pigments, of which more than 600 have been identified. In our diets, fruit and vegetables are the most important sources of vitamin A, and carotenes have been highlighted as being antioxidants. It has been found that increases in β-carotenes in crops is proportional to the supply of nitrogen.

Comparative studies find that organic crops often have lower levels of vitamin A since these crops do not receive the same amount of nitrogen.[5,7,9,29] And, fertilizing with potassium has been shown to have a positive effect on formation of carotenes. We can therefore state that levels of vitamin A are equal to or higher in conventional compared to organic crops.

Vitamin B

Comparative studies of conventional and organic crops have also shown that there is no noticeable difference in regard to levels of vitamin B. Though several studies have shown that fertilization with mineral nitrogen stimulates the synthesis of vitamin B in crops.[25]

Greater protein synthesis due to nitrogen fertilization provides higher levels of vitamin B in cereals. Understanding of the mechanism for vitamin B synthesis is still limited, however. The higher content of protein is related to higher fat content in the leaves since the formation and metabolism of fats is linked to protein synthesis. It is also known that vitamin B is needed to metabolize fats.

From this we can expect that levels of vitamin B are equal to or higher in conventional crops compared to organic ones.

Vitamin C (ascorbic acid)

Vitamin C levels in plants are linked by photosynthesis to the formation of glucose. This means that high photosynthesis activity – causing rapid formation of glucose – also stimulates the formation of vitamin C. The factors most affecting vitamin C levels are light radiation and light absorption, both of which promote vitamin C formation. Vitamin C in plants serves two functions. It is necessary for photosynthesis, and acts as protection against oxidative stress.

A review of the scientific literature shows that mineral nitrogen fertilization reduces vitamin C levels in plants.[19] But there are studies that also show the exact opposite. The literature on food quality of organically and conventionally farmed crops indicates that high protein levels often follow lower vitamin C levels.[5,7,9,29] In other words, conventionally farmed plants generally have less vitamin C. So why do vitamin C levels decrease with the increase in nitrogen supply? This can be explained by the fact that adding nitrogen results in more growth, which results in denser plant stands. Dense plant stands limit light penetration to leaves, which generally reduces photosynthesis activity per leaf. While

TABLE 6. A look at the levels of vitamin C (milligram per kilogram = mg kg^{-1}) in organically and conventionally farmed vegetables.

Country, crop and year	Vitamin C content (mg kg^{-1} fresh weight)		Organic vs conventional
	Conventional	Organic	(%)
France 1991			
Carrots	38	45	+18
Celery	73	81	+11
Spanien 1997			
Strawberries	700	720	+3
Kanada 1997			
Carrots	26	25	-4
Cabbage	538	479	-11
Kanada 1998			
Potatoes	275	262	-5
Baby corn	67	64	-4
Sverige 2000			
Cabbage	376	370	-2
Carrots	53	58	+9
Onions	80	90	+12
Peas	165	160	-3
Potatoes	213	223	+5
USA 2003			
Baby corn	28	32	+14
Frankrike 2004			
Tomatoes	121	154	+27
USA 2006			
Tomatoes	168	203	+21
Peppers	518	554	+7
Average			**+ 6.1**

total photosynthesis is greater in a dense plant stand compared to a sparse – since there are more leaves per plant, and therefore more leaf area – the concentration of vitamin C may be lower due to shading. Knowing that nitrogen fertilization promotes crop growth and that vitamin C levels depend on light intensity, the immediate understanding is that a strong plant population causes shading, which leads to less light reaching the lower leaves. And this reduces production of vitamin C in dense plant stands.

An important question, then, is how great the reduction of vitamin C levels brought on by applying nitrogen is (Table 6). Early studies from the 1940s showed that the greatest difference achieved was approximately 10 per cent lower levels with very high nitrogen fertilisation.[34] Other studies show a reduction of a few per cent with higher doses of nitrogen.[9,21,29,33] The data in Table 6 shows an average value of 6.1 percent higher vitamin C levels in organically farmed crops than conventional. This difference is relatively small considering that vitamin C levels vary considerably between different fruits and vegetables. It is also worth noting that we normally consume more than enough vitamin C in a varied diet, regardless of the type of farming.

Trace elements (micronutrients)

Another measure of quality in crops, in addition to vitamins, is their content of trace elements. Trace elements are essential elements for plants and animals, including humans. These are present in soils and plants in low concentrations (micrograms). A commonly repeated claim is that use of mineral fertilizer leads to lower levels of trace elements, and therefore lower quality. One hypothesis is that mineral fertilizer leads to dilution of trace elements in the crops due to higher yields.

Comparing levels of trace elements in organically and conventionally farmed crops provides no evidence of any clear differences. The differences reported in separate studies are inconsistent. A compilation of a large number of studies comparing organic and conventional farming shows that in 20 per cent of the cases, the organically farmed crops have higher levels. However, an equal number (20 per cent) show higher levels in conventionally farmed crops. In all other cases in this report there was no difference at all. A further observation is that the levels of trace elements in crops from different locations varies more than any differences attributable to type of farming on the same field.

This means that the field location has a greater impact on the content of trace elements than whether the crops receive mineral fertilizer or not. An important source of trace elements, therefore, is the field farmed, the underlying bedrock, and their mineral composition. If, for example, the levels of selenium are low, as is general for Scandinavia, then the selenium levels in the crops is also low, regardless of the type of farming. Selenium levels in crops can only be raised through the controlled application of fertilizer. This is done in Finland, which started applying selenium fertilizer in 1984 as public health policy. Fertilization has raised the selenium levels in Finnish crops ten times, which has also affected its prevalence in animal products, and has now reached optimal levels for health. It is interesting to note that selenium fertilization has affected the entire food chain,[14] though Finland is the only European country to achieve desired blood selenium levels in their population (Figure10).

An additional factor that affects the composition of trace elements in crops is atmospheric deposition. This involves the deposition of undesirable elements, such as cadmium and lead, which has previously been high, but has decreased significantly in recent decades due to use of lead-free petrol and the implementation of flue gas cleaning in furnaces and industry. The reduced deposition of these two heavy metals has resulted in 50 to 80 per cent lower concentrations in crops.[18]

To summarize, it can be noted that even if we want to believe that products from organic farming have higher levels of essential trace elements, this belief has no support in the scientific literature. Rather, the controlled application of fertilization is the correct method to achieve desired levels in crops. Human intake of trace elements is, as for other nutrients, determined to a sig-

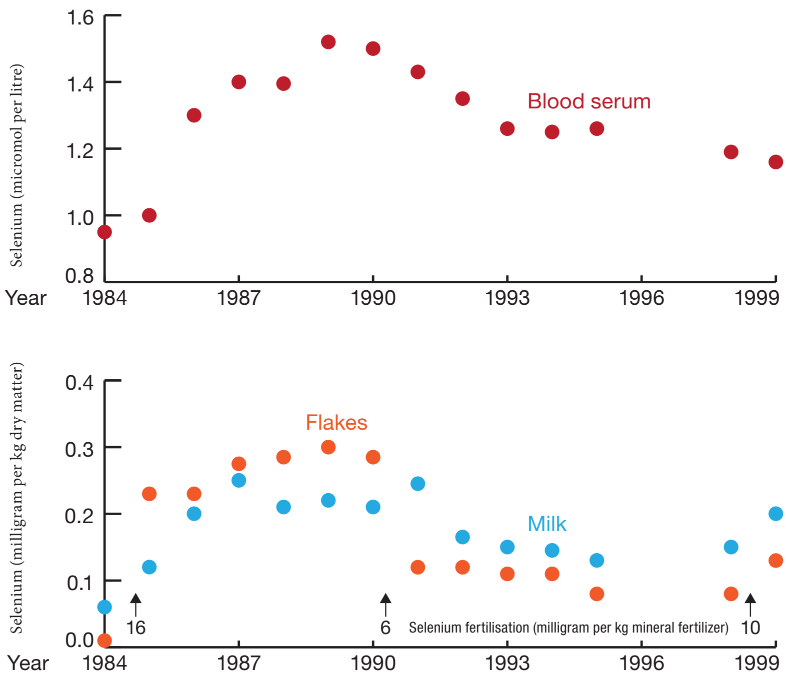


FIGURE 10. Selenium levels in Finnish cereals (spring crops), milk, and human blood serum since 1984 when selenium fertilization was started in Finland.[14] The figure clearly illustrates the relationship between selenium fertilization and the levels of selenium in blood serum in the Finnish population.

nificant degree by our choice of foods. The greatest differences involve the choice between vegetarian and omnivorous diets.

> ***A large number of studies have shown there are few differences in the composition of crops between various types of production and that only very few nutrients are affected by the type of farming. From a health perspective, these differences are at times more advantageous for organic, and at other times more advantageous for conventionally grown crops.***

Pesticides and natural toxins

Chemical pesticides are used in conventional farming to control both weeds and to protect plants from fungal infection and insect attack. Pesticides can be seen as medicine that is used in agriculture to cure disease in crops. Pesticide residues in the crops are, however, obviously not desirable. Many, therefore, think that conventional farming cannot actually produce safe and wholesome foodstuffs. Organically produced food is seen as entirely free from toxins and therefore more wholesome since no synthetically manufactured pesticides are used, only natural control methods. That organic is free from toxins and conventional has toxin residues is the common perception. From a health point of view, it would therefore appear logical to buy organic food. But even organically grown crops can contain residues of permitted pesticides.[6, 15]

In Sweden's case, there are some 70 natural pesticides used in organic farming that have pesticidal properties.[16] The EU regulation on organic farming contains a further 30 permitted substances, which include pyrethrum, copper sulphate and mineral oils. The rules for their use varies between countries. Pyrethrum is an extract from dried flowers of the chrysanthemum family that are used as an insecticide. This substance is as toxic to fish, birds and mammals as comparable synthetic insecticides.

Copper sulphate is a pesticide used against fungal infection in organic farming, but which leads to the slow concentration of copper in the soil (as has been noted on many vineyards in Europe). High copper concentrations in soil cause a significant decrease in biological activity. A comparable synthetic fungicide based on copper, and which is used in conventional farming, has a much higher toxicity. This, therefore, means that the dosage needed is much lower, thus reducing the copper load on the environment.[32] The effect of both natural or synthetic pesticides on organisms depends on the dosage and toxicity. If the substances are less toxic, the dose must be increased to achieve the same effect.

Pesticide residues can also be found in organic crops. Pesticide residues are only one group of undesirable substances in food. In nearly all the food we eat, you also find so-called natural toxins. These toxins are found in both organic and conventionally grown produce. And furthermore, these are often found in significantly higher concentrations than pesticide residues. Natural toxins are produced by the plants themselves or by fungi that live on the plants.

There is broad concern for pesticide residues in food, and for the possible negative effects these have on human health. The Swedish Chemicals Agency regulates all pesticides used in the country, in part for this reason. The Swedish National Food Agency sets limits for the highest concentrations of undesired and hazardous substances in food products. The most highly toxic substances, for both humans and the environment have been successively banned. But this situation is very different in countries that have poor regulation and lack of understanding by farmers. We know that the concentrations of the pesticides used in Sweden are extremely low in foodstuffs and have absolutely no acute toxicity.

As a result of the general concern regarding pesticide residues in produce, new varieties of plants containing lower levels of natural toxins, which are more resistant to infection have been developed through plant breeding. These new varieties need significantly less pesticides or even none at all. It is easy to believe this is the right way to go. But, it is very important to point out that greater resistance to infection in plants may be due to the plant producing more natural toxins to protect itself than the non-resistant varieties. Natural toxins are part of plants' defence mechanism against fungal infection and insect infestation. When under attack, plants often produce even more natural toxins.

Solanine in potatoes, tomatine in tomatoes, and lectines in beans are naturally occurring toxins. The Magnum bonum potato variety was found to have much higher concentrations of solanine than other potato varieties. In Sweden, and in many other countries, the limit value for solanine content is 200 mg per kilogram of potatoes. The Magnum bonum variety exceeded this limit.

Sensitive individuals can get headaches, nausea, and diarrhoea after ingesting these, so the variety had to be banned from the market. Another example is breeding celery to have a high natural resistance to insects. It was found that resistant celery contained very high levels of psoralen, a natural toxin that is also found in parsley. This substance increases susceptibility to UV radiation. Individuals who handled this celery experienced rashes because their skin's sensitivity to the radiation increased markedly. This example illustrates the dilemma, plants can be bred to produce sufficiently higher levels of natural toxins to defend themselves against infestation, but then these varieties may become too toxic for human consumption. The critical question is which can be more dangerous for humans, the presence in crops of natural toxins or of pesticide residues?

But, first it should be noted that humans have a number of protective mechanisms to buffer against exposure to these toxins. Still, there are no specific mechanisms to protect against natural toxins, despite having been exposed to these for thousands of years, whereby these mechanisms have had a long time to adapt. Natural toxins, as with the fungal toxin aflatoxin in cereals or nuts, can still cause cancer in animals and humans. All indications are that high concentrations of either natural or synthetic environmental toxins are harmful to humans.

Generally, the negative effects of toxic substances on human health are dependent on two factors: toxicity and dosage. Toxicity is approximately the same order of magnitude for natural toxins as for chemical pesticides. On the other hand, the dose we ingest is what differs. Calculations show that the amount of natural toxins are approximately 15,000 times greater than the pesticide residues

TABLE 7. Average intake of pesticide residues and natural toxins with food, and their toxicity (mg per person and day). The toxicity values are the lowest dose for which no negative biological effect can be observed in test animals (NOAEL = no observed adverse effect level). A low NOAEL value indicates high toxicity.

Substance	Food	Average intake with food mg per person and day	Highest dose intake for which no negative effect is observed (NOAEL) mg per person and day
Pesticides			
Glyphosate	Cereals	0.05	35 000
Bentazon	Cereals	0.05	224
Dimethoate	Cereals	0.01	17.5
Natural toxins			
Solanine	Potatoes	12	70
Caffeine	Coffee	70	2 800
Fungal toxins (dioxynivalenol)	Cereals	0.15	70
Reference substance			
Alcohol	Alcoholic drinks	7 400*	23 800

*Corresponds to approximately a single low-alcohol beer daily.

we consume through our food (a total of 105 pesticide residues).[2] A few calculation exercises can illustrate this. Three cups of coffee, regular or organic, contains 130 milligrams of natural toxic substances, of which caffeine is 70 milligrams. The intake through food of the three pesticides shown in Table 7 total no more than 0.11 milligrams daily, which corresponds to approximately 40 milligrams for a year. We therefore ingest less of these pesticides in an entire year than the amount of caffeine we take in with our coffee every day. Even if we had considered all possible control agents that can be found in our food, the calculation would be similar. You don't need to stop drinking coffee now, though, as this example simply provides perspective on the amounts of pesticides we risk ingesting in our food.

Since the toxicity is approximately on the same order of magnitude for natural toxins and pesticides[2] and since we take in extremely small amounts of pesticide residues, our exposure to natural toxins is much greater than these small amounts of pesticides (Table 7). For example, our exposure to the natural toxin solanine in potatoes is considerably higher than to residues of pesticides.

For another comparison, let's look at alcohol. In consuming alcoholic drinks (annual average for Sweden), we subject ourselves to 170,000 times higher exposure to toxins than we receive every year of the pesticide glyphosate, the active agent in the herbicide Round-up. The dose for no observable negative effect (NOAEL) is approximately the same for alcohol and glyphosate (Table 7). Drinking water is, of course, one of our most important foodstuffs. Its quality is controlled through strict regulation. The limit values for a pesticide in drinking water, regardless of toxicity, is 0.1 microgram per litre. If you drink 2 litres of water daily, and this contains 0.1 micrograms of pesticide residues per litre, you would have to drink that water your entire life to ingest a total of 5 milligrams of the chemical. This is approximately 100 times less than the amount of active substance you ingest in a single tablet of aspirin.

> ***Toxicity for pesticides and natural toxins is approximately on the same order of magnitude. The intake of natural toxins with food is approximately 1,500 milligrams per person and day, while the amount of pesticide residues is less than 1 milligram.***

We don't want to use these comparisons to belittle the dangers associated with use of these pesticides. But the examples above illustrate how easy it is to 'strain a gnat and swallow a camel' when discussing toxins in food. Toxins in food must be addressed comprehensively without exaggerating concern for pesticides only. We must be careful of the right things. While we know too little about natural toxins in our food, they do have an impact on our health. This also goes for toxic substances that can be formed when cooking our food (as with polycyclic aromatic hydrocarbons, heterocyclic amines, and acrylamide).

The effects of long-term exposure to very small amounts of pesticides on human health are more or less impossible to measure. Which is why governmental authorities justifiably apply the precautionary principle when assessing the risks associated with pesticides.

Other substances in our diet

Proponents of organic foods sometimes claim that other substances in our food (secondary metabolites) have positive health properties and that these substances may occur in higher levels in organically grown plants.[5] But is this really so?

'Secondary metabolites' is the generic term applied to a number of compounds such as polyphenols, terpenoids, alkaloids, flavonoids, and glucosinolates. In all, this includes between 5,000 and 10,000 substances that are formed in plants but whose function is only partially understood. In contrast to vitamins and certain trace elements, these are not essential for humans or animals, but rather appear to primarily benefit the plants themselves, including providing protection against damaging light, insect and fungal infection, and to make the plant bad tasting for herbivores. Certain of these secondary metabolites give our produce their characteristic flavours. Glucosinolates – sulphur containing substances that are secondary metabolites – are what give Brussels sprouts, cauliflower, and radishes their bitter flavour. Substance that add spice to mustard, horseradish, and wasabi are thiocyanates, and are toxic secondary metabolites – if ingested in high concentrations.

The possible function of metabolites in humans has not been established. However, it is known that certain of these can function as antioxidants. 70 years ago, it was thought that polyphenols were essential for humans and were to be designated vitamin P. No evidence that these are necessary has ever been found. Though we do know that vitamins and trace elements function as antioxidants. Polyphenols are not considered vitamins today. Several studies have postulated that phenolic substances in berries[3] and campherols in tomatoes[8] are as beneficial as vitamin C. Other toxicological studies have found that these substances are toxic.[1]

With today's understanding, it is doubtful whether these secondary metabolites can be classified as critical substances for human health. Since the total number of secondary metabolites is so large, it is also difficult to determine which substances are beneficial and which are toxic. Positive health effects of fruit and vegetables rich in secondary metabolites, may simply be an effect of getting sufficient vitamins and minerals, rather than a high intake of secondary metabolites.

In the discourse regarding secondary metabolites, we should remember that only a small number of plants are cultivated for food production. Through the millennia, people have learned which plants taste good and these have been bred to increase their nutrient content (starch, fat or protein). Humans have also bred plants in regard to eliminating substances that give an unpleasant taste or are unhealthy. High levels of undesired substances cause bitter or bad taste, or high levels of harmful secondary metabolites are why many plants are not used as food, and why plant breeding is used. Cultivated plants are therefore different from their wild cousins, particularly in regard to their content of many undesirable secondary metabolites. It is therefore an incorrect conclusion to classify secondary metabolites as an indicator of good quality.

Taste

Food should taste good, and flavour is an important property related to its quality. Scientifically controlled taste testing (sensory evaluation) enables measuring product properties more objectively when conducted as blind testing. But it is still unavoidable that the flavour experience is strongly influenced by expectation, state of mind, and even age. So, does organically produced food taste better than conventional?

A Swedish study compared organic bread with bread that used conventionally produced cereals. This found that in terms of flavour, smell, and texture, the bread made from conventionally grown flour products received higher grades and was considered moister, more elastic, and sometimes having greater volume than the organic bread.

The freshness and flavour of some vegetables also depends on the amount of time between harvest and consumption. In this, proximity to production has an important role regardless whether the produce is grown organically or conventionally. As well, the water content of fruit and vegetables influences the taste experience. High water content vegetables are experienced as less flavourful while sugar content and flavours are more concentrated in lower water content produce.

A typical example where flavour comparisons prefer organic produce is the tomato. Sensory testing has often shown clearly that organic tomatoes are more flavourful and that tomatoes from conventional farming have less flavour. Most often, though, organic tomatoes are grown in soil while conventional tomatoes are grown hydroponically. In this case, the comparison is not simply between organic and conventional methods, but rather two different ways of growing the tomatoes. That's why it is important to differentiate the factors involved in order to be able to determine any differences under scientific controls.

Diet composition instead of farming philosophy

We have discussed the quality of foods in regard to the presence and levels of essential, nutritious, and harmful substances. As our compilation shows, differences in nutritious substances are often small, sometimes conventional is better, at other times organic is. Levels of pesticide residues are lower than the prevalence of naturally occurring toxins. In short, contrary to claims that the type of production determines how wholesome the food is, there is no basis for this view in research.[19,24,31]

When you ask yourself what you should eat to provide your body with the healthiest diet, the first consideration is to emphasize the meal's ingredients. The significance of dietary composition in regard to health has long been understood. A horrifying example of the devastating health effects of poor diet is in children in impoverished situations who have swollen stomachs caused by a diet of mostly carbohydrates and lacking sufficient protein. However, the composition of diet may be unbalanced in many other ways. This includes the relationship between carbohydrates and fats, the share of fruits and vegetables, and the amounts of saturated and unsaturated foods. What determines a healthy diet apparently involves providing adequate amounts of essential nutrients. And this is done most simply by maintaining a balanced and diverse diet. Evidence suggests that an unbalanced or incomplete diet has the greatest impact on health, not the type of agriculture producing the food consumed.

Literature Chapter 4

1) Ames, B.N. (1983) Dietary carcinogens and anticarcinogens. *Science, New Series* 221, 1256-1264.

2) Ames, B.N., Profet, M. & Gold, L.S. (1990) Dietary pesticides (99.99 % all natural). *Proceedings of the National Academy of Science of the USA* 87, 7777-7781.

3) Asami, D.K., Hong, Y-J., Barrett, D.M. & Mitchell, A.E. (2003) Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry and corn grown using conventional, organic and sustainable agricultural practices. *Journal of Agricultural and Environmental Ethics* 51(2), 1237-1241.

4) Balfour, E.A. (1943) *The Living Soil*. Faber & Faber Ltd. London, England, 276 p.

5) Benbrook, C., Zhao, X., Yáñez, J., Davies, N. & Andrews, P. (2008) *New evidence confirms the nutritional superiority of plant-based organic foods.* The Organic Center, Boulder, Colorado, USA, 53 p. http://www.organic-center.org/reportfiles/5367_Nutrient_ Content_SSR_FINAL_V2.pdf.

6) Benbrook, C. (2004*) Minimizing pesticide dietary exposure through the consumption of organic food.* Report. The Organic Center, Boulder, Colorado, USA, 49 p. http://www.organic-center.org/reportfiles/PESTI- CIDE_SSR.pdf.

7) Bourne, D. & Prescott, J. (2002) A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. *Critical Reviews in Food Science and Nutrition* 42, 1-34.

8) Caris-Veyrat, C., Amiot, M-J., Tysassandier, V., Grasselly, D., Buret, M., Mikolajczak, M., Guilland, J-C., Bouteloup-Demange, C. & Borell, P. (2004) Influence of organic vs conventional agricultural practice on the antioxidant microconstituent content of tomatoes and derived purées; consequences on antioxidant plasma status in humans. *Journal of Agricultural and Food Chemistry* 52, 6503-6509.

9) Dangour, A.D., Dodhia, S. K., Hayter, A., Allen, E., Lock, K. & Uauy, R. (2009) Nutritional quality of organic foods: a systematic review. *The American Journal of Clinical Nutrition* 90, 680-685.

10) Duncan, C., Li, H., Dykhuizen, R., Frazer, R., Johnston, P., MacKnight, G., MacKenzie, H., Batt, L., Golden, M., Benjamin, N. & Leifert, C. (1997) Protection against oral and gastrointestinal diseases: Importance of dietary nitrate intake, oral nitrate reduction and enterosalivary nitrate circulation. *Comparative Biochemistry and Physiology A* 118, 939-948.

11) EFSA. (2008) Nitrate in vegetables. Scientific opinion of the panel on contaminants in the food chain. European Food Safety Authority. *The EFSA Journal* 689, 1-79.

12) Eko-Mat Centrum (2013) *Fakta, frågor och myter om ekologiskt jordbruk (Facts, questions and myths about organic farming). Informationscentrum för ekologiska produkter (Information Centre for Organic Products,Swedish only)*. Stockholm, Sweden, 14p. http://www.ekomatcentrum.se/files/Fakta%20fragor%20och%20 myter%20om%20ekologiskt%20jordbruk.pdf.

13) Eppendorfer, W.H. & Bille, S.W. (1996) Free and total amino acid composition of edible parts of beans, kale, spinach, cauliflower and potatoes as influenced by nitrogen fertilisation and phosphorus and potassium deficiency. *Journal of the Science of Food and Agriculture* 71, 449-458.

14) Eurola, M., Alfthan, G., Aro, A., Ekholm, P., Hietaniemi, V., Rainio, H., Rankanen, R. & Venäläinen, E-R. (2003) *Results of the Finnish selenium monitoring program 2000-2001.* Agrifood research reports, 36. MTT Agrifood Research Finland. Jokioinen, Finland, p. 42.

15) Felsot, A.S. & Racke, K.D. (2007) *Crop Protection Products for Organic Agriculture. Environmental, Health, and Efficacy Assessment.* ACS Symposium Series 947. American Chemical Society, Oxford University Press, Washington DC, USA, 310 p.

16) Swedish Board of Agriculture (2005) *Växtskyddsmedel i ekologisk odling (Plant protection agents in organic farming, Swedish only).* Jordbruksinformationen 24, Jönköping, Sweden, 62 p.

17) Kihlberg, I., Johansson, L., Kohler, A. & Risvik, E. (2004) Sensory qualities of whole wheat pan bread – influence of farming system, milling and baking technique. *Journal of Cereal Science* 39, 67-84.

18) Kirchmann, H., Eriksson, J. & Mattsson, L. (2009) Trace element concentration in wheat grain – Results from the Swedish long-term soil fertility experiments and national monitoring program. *Environmental Geochemistry and Health* 31, 561-571.

19) Kirchmann, H. & Bergström, L. (2012) Human health issues associated with nutrient use in organic and conventional crop production. I Bruulsema, T.W. et al. (red.) *Fertilizing Crops to Improve Human Health: a Scientific Review.* International Plant Nutrition Institute, Norcross, GA, USA, p. 241-273.

20) Leifert, C. & Golden, M.H. (2000) *A re-evaluation of the beneficial and other effects of dietary nitrate. International.* Fertiliser Society, Proceedings No. 456. England.

21) Lisiewska, Z. & Kmiecik, W. (1996) Effect of level of nitrogen fertilizer, processing conditions and period of storage for frozen broccoli and cauliflower on vitamin C retention. *Food Chemistry* 57, 411-414.

22) Lundberg, J. O., Weitzberg, E., Cole, J. A. & Benjamin, N. (2004) Opinion-Nitrate, bacteria and human health. *Nature Reviews Microbiology* 2, 593-602

23) Lundberg, J. O., Weitzberg, E. & Gladwin, M. T. (2008) The nitrate-nitrite-nitric oxide pathway in physiology and therapeutics. *Nature Reviews Drug Discovery* 7, 156-167.

24) Magkos, F., Arvaniti, F. & Zampelas, A. (2003) Organic food: nutritious food or food for thought? A review of the evidence. *International Journal of Food Sciences and Nutrition* 54, 357-371.

25) 74Mengel, K. & Kirkby, E.A. (2001) *Principles of Plant Nutrition*. 5utg. Kluwer Academic Publishers, Dordrecht, Nederländerna. 849 p.

26) Mozafar, A. (1993) Nitrogen fertilizers and the amount of vitamins in plants: a review. *Journal of Plant Nutrition* 16, 2479-2506.

27) Rosen, J.D. (2008) *Claims of Organic Food's Nutritional Superiority: a Critical Review*. American Council on Science and Health. New York, NY, USA, 13 p. http://www.acsh.org/docLib/20080723_claimsoforganic.pdf.

28) Rusch, H.P. (1978) *Bodenfruchtbarkeit. Eine Studie biologischen Denkens (German only)*, 3 utg. Haug Verlag, Heidelberg, Tyskland, 243 p.

29) Smith-Spangler, C., Brandeau, M. L., Hunter, G.E., Bavinger J. C., Pearson, M., Eschbach, P.J., Sundaram, V., Liu, H., Schirmer P., Stave, C., Olkin, I. & Bravata, D.M. (2012) Are Organic Foods Safer or Healthier Than Conventional Alternatives? A Systematic Review. *Annals of Internal Medicine* 157, 348-366.

30) Steiner, R. (1924) *Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft (Spiritual Foundations for the Renewal of Agriculture, German only).* Rudolf Steiner Nachlassverwaltung, 5 edition. Auflage 1975, Dornach, Tyskland, 256 p.

31) Tinker, P.B. (2000) *Shades of Green – A Review of UK Farming Systems*. Royal Agricultural Society of England (RASE). Natural Agricultural Centre, Stoneleigh Park, Warwickshire, England, 100 p.

32) Trewavas, A. (2004) A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture. *Crop Protection* 23, 757-781.

33) Woese, K., Lange, G., Boess, C. & Bögl, K.W. (1997) A comparison of organically and conventionally grown foods – results of a review of the relevant literature. *Journal of the Science of Food and Agriculture* 74, 281-293.

34) Åberg, B. & Ekdahl, I. (1948) Effect of nitrogen fertilization on the ascorbic acid content of green plants. *Physiologia Plantarum* 1, 290-329.

5

What about soil fertility and sustainable production capacity?

Fertile soils – the active soils that have high productive capacity – are characterized by their good nutritional status, good water retention capabilities, good soil structure, suitable pH levels, and being rich in organic matter.[25] To prevent declining yields and enable sustainable production of adequate amounts of food, soil fertility must be preserved, and preferably improved. This can be achieved under a few basic conditions:

- Plant nutrients removed in agricultural products must be replaced to ensure that stocks of plant available nutrients in soil are not depleted.

- Competition from weeds must be controlled.

- Harmful organisms in the soil that cause plant diseases must not be allowed to propagate.

- The soil structure cannot be impaired.

When plant nutrients are not applied to compensate for actual losses due to removal through harvesting and leaching, soil will be depleted, and yields will inevitably decline due to the lack of specific nutrients – much like a Ponzi scheme is built on unsustainable inflows of capital. Soil structure is equally important, as it determines how well plants' root systems can develop.

Dense, compacted soils restrict root development, reducing plants' capacity to utilize water, air, and plant nutrients. Another important component in sustainable farming is efficient recirculation of plant nutrients from urban waste back to farmlands to the greatest extent possible. This can provide crops the nutrients they need.

The following discussion explains how organic farming affects soil fertility and sustainable production capacity, and the problems that may arise. The popular claim is that organic farming guarantees sustainable food production,[13] and moreover, that this is not the case for conventional farming. Is this correct?

Different approaches to fertilization

Organic and conventional farming differ in their approach to fertilization, and this arises from differing understanding of how the soil-plant system functions. In organic farming, fertilizing the soil is emphasized, whereby the fertile soil then provides all necessary nutrition to crops. Crops should not be fertilized directly in this approach. Instead, fertilizer reaches the plants indirectly through the breakdown or decomposition of organic fertilizer or untreated minerals into the soil, where nutrient salts are released. This idea asserts the existence of harmonious interaction between the soil and crops, which enables the optimal release of nutrients. Conventional farming emphasizes both crop requirement and soil fertility. Fertilization is therefore primarily intended to satisfy nutrient demand in the crops by applying the correct type and amount of plant nutrients based on anticipated yield and soil analysis.

The preconception that indirect fertilization occurs through improving soil fertility, thereby guaranteeing optimal delivery of nutrients to the crops, is not based on scientific findings. Chemical and biological processes in the soil determine its delivery capacity, and these processes are driven by several factors in the soil, including temperature, moisture, microbial metabolism, and mineralogical composition.

The capacity of soils to deliver nutrients also varies over the years, so generally, they do not deliver adequate amounts of every nutrient that a crop may need in any given season.[20] In conventional farming, the focus is therefore on providing the crop with sufficient nutrients to meet their production capacity – and to improve soil fertility.

Soil fertility changes slowly

Changes to soil fertility are very slow. Amendment or depletion of plant nutrient stocks in soil can most often only be measured after 5 to 10 years, and these processes can extend over several decades.[16,23] This makes it impossible to establish conclusively whether changes in fertility or long-term yield effects have occurred after only a few years of study. Long-term field trials have therefore been conducted around the world, and these have shown that adaptive fertilization involving both organic and mineral fertilizer, and suitable farming measures, improve soil fertility.

A Norwegian study of organic farming in Apelsvoll found yield reduction only after 10 years.[8] If they had ended the trial sooner, any conclusions would have been incorrect. Early in this trial, the soil contained very high levels of organic material, which gave high yields for several years, as the soil delivered plenty of nutrients. After a portion of the humus capital had been consumed, yields began to decrease.

In relation to organic farms with only crop production (and no animal keeping), the removal of plant nutrients, as with phosphorus and potassium, is greater on average than is added, resulting in soil depletion.[4,10] Estimates from organic farms in Sweden and other European countries have shown that a deficit of 7 kilograms of phosphorus and 22 kilograms of potassium per hectare

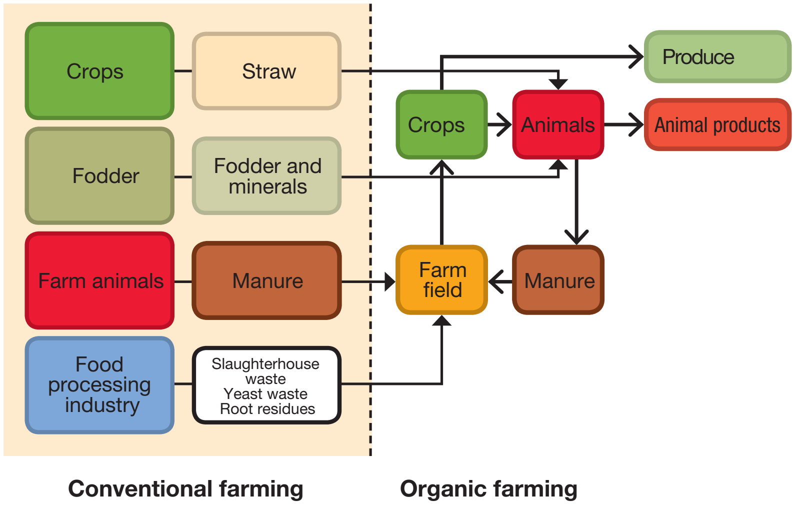


FIGURE 11. Organic farming is dependent on products from conventional farming to supply crops and farm animals with nutrients. Without conventional farming, there would not be sufficient volumes of these products.

and year.[20] Therefore, over the long-term, organically farmed soils become depleted of plant available nutrients.

Moreover, it is almost impossible to maintain fertility in organic systems without animals. If, instead, approved organic fertilizer purchased from outside the farm is applied to prevent soil depletion,[9,32] these fertilizers are most often poorly soluble, and plant available nutrients in the soil do not increase.[19,24]

Some claim that organic farming increases humus levels, and that growing green manure crops can improve the humus balance. But this is not the case.[10] Lower yields generate less crop residues (roots and above ground plant parts) which are the raw material needed for humus formation. Instead, lower yield levels lead to a decrease in soil humus content on organic farms with no animal keeping.[22]

The situation is different for organic farms that do keep animals. Generally, these do achieve balance between the addition and removal of plant nutrients since these farms often buy mineral and other feedstuffs, along with straw and various kinds of organic fertilizer.[4,9,26,27,32] Purchasing these products from sources external to the farm brings in a substantial supplement of plant nutrients. But these products generally originate from conventional production (Figure 12). This also makes organic animal farms partially dependent on plant nutrients from mineral fertilizer.

A variation of this type of farming is combining conventional animal keeping with growing crops organically on the same farm. Under this practice, conventional, bought feedstuffs become the source of the manure used in organic farming. The rules covering the types of fertilizer originating from conventional farms which may be brought onto organic farms are continually under discussion, and changed from time to time. To the extent natural pasture land is used for grazing, nutrients are also transferred from the pastures to the animal products sold.

Organic farms need products from conventional production for their supply of plant nutrients. Despite buying conventional products, it is impossible to maintain fertile and productive soils following organic crop production practice.

If the entire agriculture sector were converted to organic production, there would be no products at all to buy from conventional production.

How are plants supplied with nutrients, and how are these recirculated within organic farming?

The significant difference between organic and conventional systems is that only manure, compost, green manure, and non-chemically modified minerals are used in organic systems, while

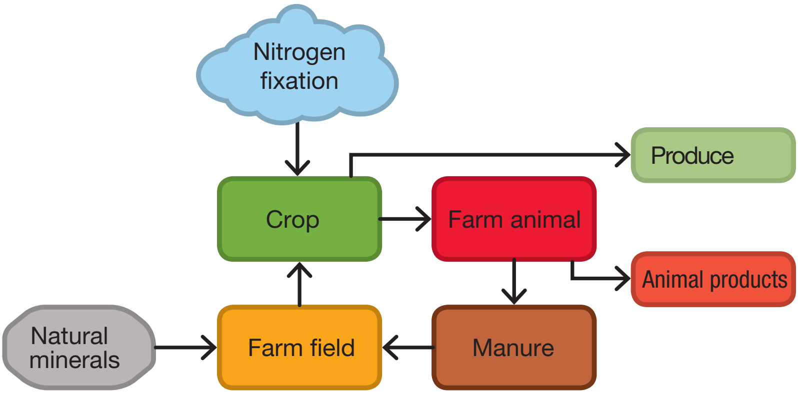


FIGURE 12. The ideal image of plant nutrient supply in organic farming.

conventional systems use both organic and mineral fertilizer. Organic farming holds that recirculation of plant nutrients within the farm, the addition of airborne nitrogen through fixation by legumes, the application of untreated minerals, and mineral weathering in the soil meets crop needs, preserving delivery of nutrients through soil (Figure 12).[12] In biodynamic farming, the farm must be a self-sufficient unit without the need to buy any plant nutrients or animal feed.[15,29]

But in most soils, these mechanisms do not adequately preserve fertility at existing yield levels. When organic farms with high yields are referenced as evidence that nutrient supply is adequate, these most often are located on soils with naturally high content of these nutrients. These are known as organogenic or humus rich mineral soils. These soils are, however, the exception. In these, nutrient stocks have been built up through the millennia, which can be exploited to supply crops with adequate nutrients for several decades without fertilization. Such soils make up less than 10 per cent of Sweden's farm acreage and are not representative of the vast majority of farmlands.[3]

Nitrogen is the most important nutrient for crops and is needed for protein synthesis. Organic farms acquire nitrogen primarily through legumes. Legumes bind nitrogen gas from the air to providing their own requirements, and they therefore do not need an external supply. These plants coexist with nitrogen-fixing bacteria that live in their roots and this symbiosis meets their nitrogen needs. This biological process is therefore known as symbiotic nitrogen fixation. Legumes are a very important part of crop rotation as 1) feed crops (clover and alfalfa (lucerne)) for cattle whose manure is applied to fields, 2) as peas and beans for human consumption, or 3) as green manure crops.

Crop residues from legumes are also used to supply nitrogen to other crops in the rotation when they decompose in the soil. A leguminous crop can fix nitrogen on the order of magnitude of 400 kilograms of nitrogen per hectare annually,[7] though, a normal nitrogen application rate for conventionally grown crops is approximately 100 kilograms per hectare and year.

Ploughing down crop residues or all the plant material (as with green manure), generally provides a quick increase in the amount of plant available nitrogen in the soil. A problem here, however, is that the amount of nitrogen fixed biologically cannot be controlled, and neither can the amounts released through decomposition. This creates a surplus that the subsequent crops in the rotation cannot take up. In addition, leguminous nitrogen is released off-season in autumn and winter,[19] when leaching is most likely. The amounts of nitrogen remaining in the soil is then insufficient to meet crop requirements the following year.

There is simply no adequate means to synchronize the release of nutrients through decomposition (of ploughed down legumes), and the subsequent uptake of these nutrients by crops the following year. The common misconception is that organic fertilization and plant nutrient circulation interact in harmony.

But this is not so.[20] In short, despite being able to capture airborne nitrogen seemingly for free, many studies have shown that nitrogen deficiency is what most manifestly limits yields in organic farming, specifically because of the difficulty in controlling its fixation and release from leguminous crops.[19]

More difficult still, is supplying crops with other nutrients in organic farming. Enabling long-term self-sufficiency of phosphorus, potassium and sulphur is impossible.[2,4,10,26,27,32] Relying on mineral weathering to meet the requirements of micronutrients is not a sustainable strategy. These need to be supplied externally to prevent soil depletion. Removal of nutrients must be compensated by their application. Using manure from on-farm animals simply recirculates plant nutrients, but adds nothing. Farm animals are not 'fertilizer factories', as argued at times when promoting organic farming. The amount of plant nutrients in manure will never be greater than that contained in harvested products, or in feed bought externally for the farm.

Buying untreated minerals, which are very poorly soluble (such as raw phosphate as phosphorus fertilizer), have no or very little nutritional impact on crops.[19] Further, nutrients are released very slowly from composted organic material, which is why compost is classified as a soil improver rather than fertilizer.[21]

Many organic farmers have understood this and therefore buy several types of fertilizer and feedstuffs from external sources. But these often originate from products produced conventionally. For example, slaughterhouse waste is often used as phosphorus fertilizer, and yeast waste provides a source of potassium (vinasse).[24] Moreover, feed minerals, straw, and manure are commonly imported from conventional farms.[26,27,32] The external purchase of these fertilizers and feedstuffs for organic farms involves transferring plant nutrients from conventional to organic farms. Again demonstrating dependency on conventional farming (Figure 11).

Full-scale organic farming in Sweden would therefore not have sufficient amounts of these fertilizers to purchase, and the related significant shortage of plant nutrients would lead to even lower yields. Conventional farming compensates for losses (including from the sale of harvest products) with the purchase of external mineral fertilizer, sustaining the long-term production capability of the soil.

The concept of self-sufficiency is certainly highly attractive, but in reality, organic farms are subject to the same natural laws as conventional agriculture.[30,31] Early human agriculture was characterized to a significant degree by the search for plant nutrients (see Chapter 1). Untouched forests were burned to be farmed for a shorter period (slash and burn farming). Forest grazing was common. Meadows provided harvested plant nutrients to the farm, which as we noted, gave rise to the Swedish expression we mentioned earlier, that 'meadows are the mother of cropland.'

Historically, humans utilized plant nutrients from natural ecosystems that were still much more extensive than cultivated fields. The amount of material, however, was never enough to maintain fertility in farmlands. And the transfers to these fields contributed to depletion of nearby natural systems. In many developing countries, gathering various types of plant material, soil from termite mounds, ash from burning of organic material, and similar, is still commonly used to supply plant nutrients needed for crops. The history of agriculture shows that soil fertility can only be marginally improved through natural means with local resources. The same situation that prevailed in Europe of the 1800s now exists in many African countries. Depleted soils and insufficient supply of plant nutrients for crops are causing low yields and shortages of food.

Plant nutrients added to organic systems do not meet crops' production capacity since the release of nutrients from organic fertilizers and untreated minerals is less than that provided by more soluble mineral fertilizers. This is an important explanation for why yields are significantly lower in organic than conventional systems.

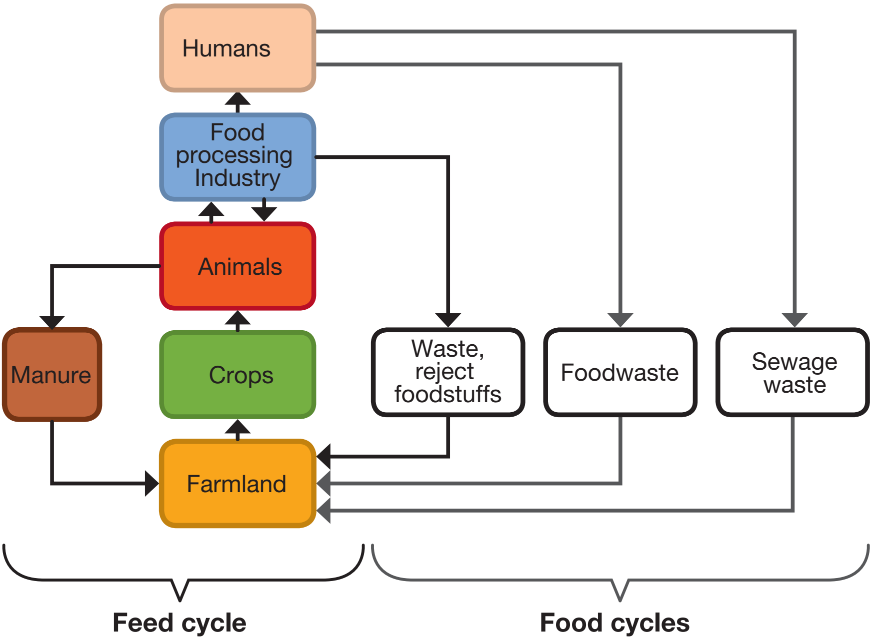


FIGURE 13. The plant nutrient cycle within society. Return flows of plant nutrients from food waste and sewage to farmland does not function despite many improvements.

Recycling plant nutrients is seen as a prerequisite for sustainable organic agriculture.[13] But how does recirculation really work?

The efficient recycling of plant nutrients to farms is the general ambition of agriculture regardless of farming philosophy. This is done by using harvested feed crops for animals to consume, whose manure is returned to the fields, and by crop residues such as straw and roots that are ploughed down into the soil. But, as we just noted, animals are not fertilizer factories. The nutrients in animal manure can never exceed what is added in their feed. If no feed is bought externally, then at the end of the day, it is the size of the yield that determines how much nutrients are available in manure.

However, plant nutrients are constantly removed from every farm's nutrient cycle through the sale of crops and animal products. This is generally the greatest outflow of plant nutrients from a farm. Once in the hands of society-at-large, these foodstuffs are transformed into waste products, either as foodstuff wastage, food waste, or sewage. As we contend, the return flows of plant nutrients from society's waste to agriculture is a prerequisite for sustainable production (Figure 13).[18]

A closed foodstuffs cycle, where nutrients transferred to society as food are recycled to farmlands from waste, is equally important for both conventional and organic agriculture. But this does not function well in practice at present.

Recirculating society's waste is associated with certain risks (as with heavy metals, organic environmental toxins, infectious agents, and medicine residues in sewage sludge). These pollutants in waste have long been a barrier to recirculation. Every type of agriculture prefers to not apply polluted waste to farm fields as this threatens long-term soil fertility. Organic farming forbids the use of sewage such as wastewater sludge, human urine, and sludge from septic tanks. This substantially hollows the nutrient cycle concept behind organic farming, but plant nutrient flows from city to farmland does not work in conventional farming either.

Future plant nutrient cycles between cities and the countryside with conventional farming

Population growth and urbanization are changing the prerequisites for recirculation of plant nutrients between cities and the country side. Urban areas are centres of consumption – where urban dwellers are supplied with foodstuffs from extensive agricultural lands, often far from cities. Metropolitan areas are also growing larger and many cities will grow past the million population mark within the next 50 years. Plant nutrients in foodstuffs taken up from the ground by food crops become urban waste.

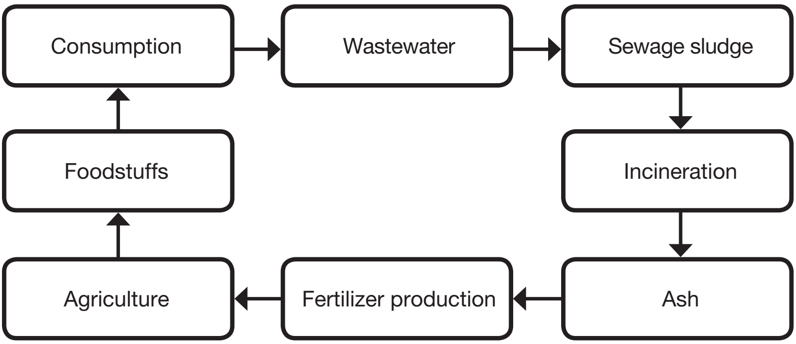


FIGURE 14. Incineration of wastewater sludge, recovering plant nutrients from the ash, and producing fertilizer can be a way forward to closing the food ecocycle for society.

Recirculating waste from urban areas back to farmlands has become too expensive due to transport costs. This also involves the risk of pollutants, presenting barriers to achieving a nutrient cycle through recirculation of urban waste.

Waste is often incinerated in larger cities to reduce its volume and the need to landfill, which is seen as the most acceptable solution for treating waste in a sanitary and practical way. Incineration is a safe way to eliminate organic environmental toxins and medicine residues. Ash from waste incineration will then be the primary residual product from cities in the future. This ash still contains most of the plant nutrients in waste, except for nitrogen and sulphur, which are lost as gas. A more realistic approach is therefore to use the ash to recover plant nutrients in order to close the plant nutrient cycle between city and countryside.

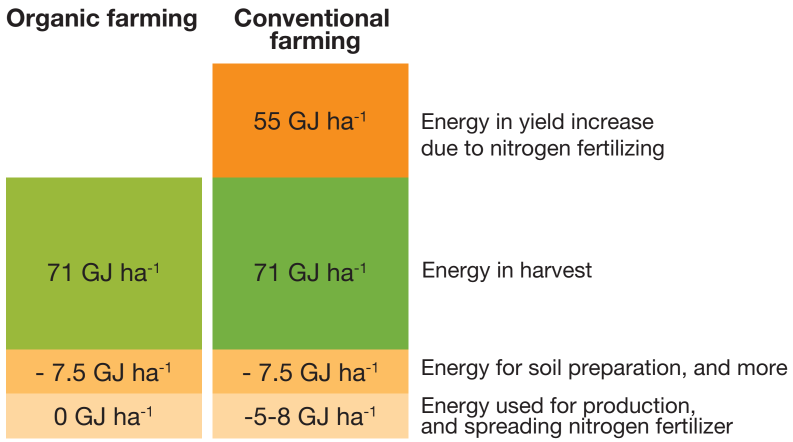
However, certain principles must be followed to achieve a functioning cycle of this kind. Recycled plant nutrients must be environmentally friendly.[17] The plant availability of these nutrients should be high in order to preserve soil fertility.[17] The amount of plant nutrients recycled to farmlands must be related to their removal in harvested crops, following the 'principle of replacement'. This would necessarily involve long transports back to distant farmland to avoid these nutrients being used only to enrich fields closer to cities. Another criterion is that this reallocation back to farmland should be sustainable from both an energy and economic standpoint.

It is obvious that returning organic waste directly to farm fields is not viable. Recovery of nutrients from waste (through production of cycle-based mineral fertilizer) may, however, be a future solution. Recent developments have brought technology that can extract and separate phosphorus from heavy metals, and other pollutants in ash to produce unpolluted water soluble phosphorus fertilizers. Extracted heavy metals and destroyed organic pollutants will thus be prevented from being recycled (Figure 14).[6,17] A functioning nutrient cycle could probably be achieved through the production of soluble mineral fertilizer produced from organic urban waste.

Even if the ban on use of organic waste containing human excrement were removed for organic farming, a viable cycle would still not be possible using organic urban waste for the reasons provided above. The ban on soluble mineral fertilizer is a fundamental principle in organic agriculture and it is hardly likely that an cycle-based soluble mineral fertilizer would be permitted, as this is chemically the exact same substance that is banned already. Our conclusion is that conventional farming presents the best prerequisites for enabling such a closed city-to-countryside cycle.

The reliance of conventional agriculture on fossil energy for production of nitrogen fertilizer

Organic farming is often presented as a sustainable form of production. The sustainability of conventional farming is, on the other hand, questioned due to its reliance on finite natural resources and an industrial production, and that pesticides require industrial production. It is taken for granted that excluding conventional



FIGUR 15. Energy balance (Gigajoule per hectare = GJ ha^{-1}) for plant production using nitrogen fertilization (conventional) and with legumes (organic).[5]

production methods guarantees greater sustainability and less environmental load.[28] But is this really so?

Nitrogen fertilizer is currently produced using fossil fuel, and consumes relatively large amounts of energy. Nitrogen is taken from the air, so only energy resources are required. The ability to replace nitrogen fertilizer with biological nitrogen fixation through legumes, as promoted in organic farming, is therefore seen as an obvious and necessary solution.[13,31]

However, close analysis of the energy balances involved provides a different understanding. Generally, the energy humans add to farming is much less than the solar energy bound into the crops. Fertilizing with nitrogen is therefore in fact an especially energy positive activity. The amount of energy required to produce nitrogen fertilizer is much less than the increase in the energy harvested through nitrogen fertilization. The average amount of energy in the 'yield increase' is 8 to 15 times greater than that used in manufacturing the nitrogen fertilizer (Figure 15).[5]

PHOTO 1. Mayweed and coltsfoot in organic winter wheat, Uppland 2009. Photo: Holger Kirchmann.

Still, this positive energy balance doesn't address the fact that non-renewable energy is used as input. Therefore, nitrogen fertilization cannot be a solution for future agriculture. Independence from fossil energy is a prerequisite for sustainable farming practice. However, fossil energy can be replaced with renewables in the production of nitrogen fertilizer. This has been done in Norway, where hydro-power was used in production instead of natural gas. This possibility is still available. Another alternative to fossil energy is gasification of biofuels. A lifecycle analysis of the biofuel alternative has shown that it takes 2.7 kilograms of straw or 2.6 kilograms of energy forest (Salix) to produce 1 kilogram of nitrogen.[1] This means that approximately 1.6 tonnes of nitrogen can be produced with the straw from a single hectare of winter wheat. The corresponding amount of nitrogen fertilizer from a single hectare of energy forest is 3.9 tonnes.

This shows that the production of nitrogen fertilizer can be

PHOTO 2. Thistles amount organic barley, Uppland 2009.
Photo: Holger Kirchmann.

based on renewable energy. In other words, future agriculture can sustainably use nitrogen fertilizer even without fossil energy.

> ***Nitrogen fertilization increases plant production and can produce more energy than is needed to manufacture, transport, and apply the nitrogen fertilizer. Nitrogen fertilizer can also be manufactured using renewables, and will therefore be a cornerstone in future agriculture production.***

Problems with weeds

Travelling through Sweden in summer, the experienced eye sees a striking change to the agricultural landscape. Many more fields are now overgrown with many varieties of weeds, not least thistles, and crops appear in sparse stands. (Photo 1 and 2). It is in-

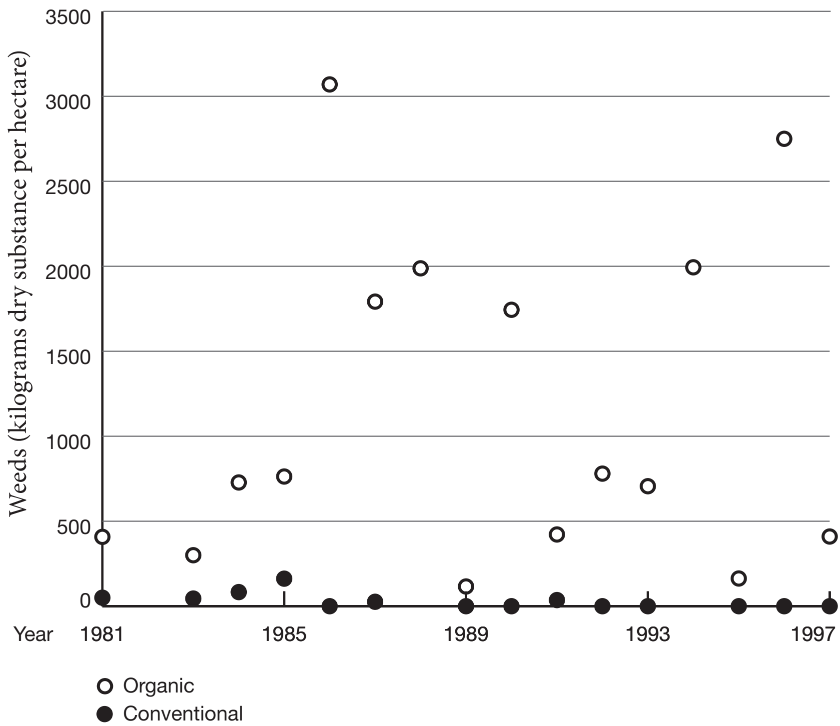


FIGURE 16. The amount of weeds in organic farming (1 ton dry substance per hectare and year on average), increases over time, while the amount of weeds in conventional farming remains constantly low.[19]

teresting that the Swedish botanist, Carl von Linnaeus made the same observation about weeds infesting farm fields in his travels through 1700s Sweden. The modern observation is of organic farmed fields where weeds can be as or more prevalent than the actual crop. The difference between conventional and organically farmed fields is readily observable due to the successive propagation of weed seeds in organically farmed fields after conversion, when herbicides are no longer used. Mechanical weed control alternatives have not been adequate in holding weed proliferation in check. Many organic farmers feel their hands are tied in their struggle against weeds. And this is therefore the primary reason many of these farmers give up and return to conventional farming.

In a long-term field trial in southern Sweden, where intensive mechanical weed control was used, the prevalence of weeds was up to 3 tonnes of biomass (dry substance) per hectare when a non-competitive crop was grown. This amount of weeds equalled the biomass of the crop. The trial covered 18 years and also showed that the amount of weeds increased over time in organic farming (Figure 16).[19] Thistle and couch grass dominated in the final years. Such a large propagation of weeds can take decades to develop. But, this seems to have occurred in many Swedish organic fields over the last 5 to 10 years.

The propagation of weeds, resulting in a huge store of seeds in farm fields, causes wide-ranging problems. Weeds compete with crops for light, water and plant nutrients, which results in a substantial reduction in yields.[14] Weeds prevent the crop from spreading out both above and below ground, whereby the crop's growth is inhibited. The risk for fungal infection also increases with excessive weeds, since the green plant parts retain moisture that promotes fungal growth. The ability of organic farming to control weed populations appears limited, especially for perennial weeds like thistle and couch grass. The possibilities are limited to: 1) Putting land into fallow for several years in the rotation of crops; 2) Intensive soil preparation; and 3) Possibly, growing fodder crops that are cut several times. In short, weed rich stands are a threat to sustainable production and also partly explain lower yields in organic farming.

The problem of sustainability

To summarize, we can say that organic farming has difficulty maintaining soil fertility, increasing recirculation of plant nutrients, and controlling weeds.

This difficulty has specific consequences. Yields in organic farming will not increase in the longer term, more likely they will decline. The variation in yield from year to year will be greater with organic farming. Both of these circumstances are due to the inability of organic farming to control the soil's capacity to deliver nutrients to crops (decomposition of humus, green and animal manure), which then depends on annual seasonal variations. The greater likelihood of reduced yields naturally means less food security. It is important to remember that even if organic farming can sustainably produce low yields, food requirements will still not be met. The concept of *sustainability* in the context of agriculture only has meaning if it includes adequate production to meet existing food needs. Neither can food production be sustainable if it contributes to environmental deterioration, as we detail in Chapters 6 and 7.

Why are yields much lower for organic as opposed to conventional farming?

- ***Lower inflow of nutrients***
  There is not enough organic fertilizer even when it is bought externally from conventional farm production.

- ***Lower effciency of organic fertilizer and untreated minerals***
  Organic fertilizer and untreated minerals do not release plant nutrients the same as soluble mineral fertilizer.

- ***Greater pressure from weeds***
  Weeds compete with the intended crop for water, nutrients and light.

- ***Less plant protection***
  Biological plant protection is most often less effective.

Literature Chapter 5

1) Ahlgren, S., Bernesson, S., Nordberg, Å. & Hansson, P-A. (2009) Ammonium nitrate fertilizer production based on biomass – environmental effects from a life cycle perspective. *Bioresource Technology* 99, 8034-8041.

2) Askegaard, M. & Eriksen, J. (2000) Potassium retention in an organic crop rotation on loamy sand as affected by contrasting potassium budgets. *Soil Use and Management* 16, 200-205.

3) Berglund, Ö., Berglund, K. & Sohlenius, G. (2009) *Organogen jordbruksmark i Sverige 1999-2008 (Organogenic Agricultural land in Sweden, Swedish only).* Swedish University of Agricultural Sciences, Departmentof Soil and Environment, Section for Hydrotechnology, report 12 Uppsala, Sweden, 27 p.

4) Berry, P., Stockdale, E., Sylvester-Bradley, R., Philipps, L., Smith, K., Lord, E., Watson, C. & Fortune, S. (2003) N, P and K budgets for crop rotations on nine organic farms in the UK. *Soil Use and Management* 19, 112-118.

5) Bertilsson, G., Kirchmann, H. & Bergström, L. (2008) Energy analysis of conventional and organic agricultural system. I Kirchmann, H. & Bergström, L. (red.) *Organic Crop Production – Ambitions and Limitations.* Springer, Dordrecht, Nederländerna, p. 173-188.

6) Cohen, Y., Kirchmann, H. & Enfält, P. (2011) Management of phosphorus resources – historical, perspective, principal problems and sustainable solutions. I Kumar, S. (red.) *Integrated Waste Management Volume II.* Open Access, p. 247-268. www.intechweb.org.

7) Dahlin, S. & Stenberg, M. (2010) Cutting regime affects the amount and allocation of symbiotically fixed N in green manure leys. *Plant and Soil* 331, 401-412.

8) Eltun, R., Korsaeth, A. & Nordheim, O. (2002) A comparison of environmental, soil fertility, yield, and economical effects in six cropping systems based on an 8-year experiment in Norway. *Agriculture Ecosystems and Environment* 90, 155-168.

9) Fowler, S.M., Watson, C.A. & Wilman, D. (1993) N, P and K on organic farms: herbage and cereal production, purchases and sales. *Journal of Cereal Science* 120, 353-360.

10) Gosling, P. & Shepherd, M. (2005) Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. *Agriculture Ecosystem and Environment* 105, 425-432.

11) Goulding, K., Stockdale, E. & Watson, C. (2008) Plant nutrients in organic farming. I Kirchmann, H. & Bergström, L. (red.) Organic Crop Production – Ambitions and Limitations. Springer, Dordrecht, Nederländerna, p. 73-88.

12) GeoHive (2010) Population statistics for agglomerations over 750,000 inhabitants. http://www.geohive.com/earth/cy_aggmillion2.aspx

13) Granstedt, A. (1985) *Naturresursbevarande jordbruk. (Natural resource preserving agriculture, Swedish only)* LT Förlag, Stockholm, Sweden, 136 p.

14) Håkansson, S. (2003) *Weeds and Weed Management on Arable Land: An Ecological Approach.* CABI Publishing, Wallingford, England, 274 p.

15) Kaffka, S. & Koepf, H. (1989) A case study on the nutrient regime in sustainable farming. *Biological Agriculture and Horticulture* 6, 89-106.

16) Kirchmann, H. & Cohen, Y. (2011) Fosforåtervinning ur avloppssystem i framtiden – rena och växttillgängliga produkter. (Future phosphorous recovery from wastewater systems - pure and plant available products) I Jakobsson, C. (red.) Återvinna fosfor – hur bråttom är det? (*Recovering phosphorous - How soon? Swedish only*) Formas Fokuserar. Edita AB Tryck, Stockholm, Sweden, p. 321-338.

17) Kirchmann, H., Bergström, L. & Andersson, R. (2010) Uthållig matproduktion på tre ben – mängd, kvalitet och miljö. (Sustainable food production on three legs -- volume, quality, and environment) I Jakobsson, C. (red.) *Jordbruk som håller i längden. (Agriculture that lasts, Swedish only)* Formas Fokuserar. Edita AB Tryck, Stockholm, Sweden, p. 91-111.

18) Kirchmann, H., Bergström, L., Kätterer, T., Mattsson, L. & Gesslein, S. (2007) Comparison of long-term organic and conventional crop-livestock systems in a previously nutrient-depleted soil in Sweden. *Agronomy Journal* 99, 960-972.

19) Kirchmann, L., Kätterer, T. & Bergström, L. (2008) Nutrient supply in organic agriculture – plant - availability, sources and recycling. I Kirchmann, H. & Bergström, L. (red.) *Organic Crop Production – Ambitions and Limitations.* Springer, Dordrecht, Nederländerna, p. 89-116.

20) Kätterer, T., Börjesson, G. & Kirchmann, H. (2014). Changes in organic carbon in topsoil and subsoil and microbial community composition caused by repeated additions of organic amendments and N fertilisation in a long-term field experiment in Sweden. *Agriculture, Ecosystems and Environment* 189, 110-118.

21) Leifeld, J. & Fuhrer, J. (2010) Organic farming and soil carbon sequestration: what do we really know about the benefits? *Ambio* 39, 585–599.

22) Løes, A.K. & Øgaard, A.F. (2001) Long-term changes in extractable soil phosphorus (P) in organic dairy farming systems. *Plant and Soil* 237, 321-332.

23) Lundström, C. & Lindén, B. (2001) *Kväveeffekter av humanurin, Biofer och Binadan som gödselmedel till höstvete, vårvete och vårkorn i ekologisk odling. (Nitrogen effects of human urine and fertilizers containing meat bone meal (Biofer) or chicken manure (Binadan) as fertilizers applied to winter wheat, spring wheat and spring barley in organic farming, Swedish only)* Swedish University of Agricultural Sciences, Department for Agricultural Sciences, Skara. Serie B, Mark och växter; rapport 8 (Series B, Soil and Plants; report 8). Skara, Sweden, 52 p.

24) Naturvårdsverket (Swedish EPA) (1994) *Markens bördighet. Vad är bördighet och hur påverkas den? (Fertility of the soil. What is fertility and how is it impacted? Swedish only)* Rapport 4337. Formas Fokuserar, Stockholm, Sweden, 150 p.

25) Nowak, B., Nesme, T., David, C. & Pellerin, S. (2013) To what extent does organic farming rely on nutrient inflows from conventional farming? *Open Access, IOP Publishing, Environmental Research Letter* 8, 044045.

26) Nguyen, M.L., Haynes, R.J. & Goh, K.M. (1995) Nutrient budgets and status in three pairs of conventional and alternative mixed cropping farms in Canterbury, New Zealand. *Agriculture Ecosystems and Environment* 52, 149-162.

27) Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, F.J., Hansen, J., Walker, B., Liverman, D., Richardson, D., Crutzen, P. & Foley, J. A. (2009) A safe operating space for humanity. *Nature* 461, 472-475.

28) Steiner, R. (1924) *Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft (Spiritual Foundations for the Renewal of Agriculture, German only).* Rudolf Steiner Nachlassverwaltung, 5 edition. Auflage 1975, Dornach, Tyskland, 256 p.

29) Stockdale, E.A., Shepherd, M.A., Fortune, S. & Cuttle, S.P. (2002) Soil fertility in organic farming systems – fundamentally different? *Soil Use and Management* 18, 301-308.

30) Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R. & Rays, F.W. (2002) Managing soil fertility in organic farming systems. *Soil Use and Management* 18, 239-247.

31) Wieser, I., Heß, J. & Lindenthal, T. (1996) Nutrient balances on organically managed grassland farms in Upper Austria. *Die Bodenkultur* 47, 81-88.

6

How does organic farming impact our waters?

A dominant view long argued by many who promote organic farming holds that this type of farming is better for our waters.[11] Leaching of plant nutrients to surface and ground waters, probably the greatest single problem for agriculture today, is said to be reduced with organic farming.[10] As well, organic farming is offered as a solution to reduce agriculture's load of plant nutrients to the Baltic Sea[11], and, this load is substantial.

Estimates show that approximately 50 per cent of all phosphorus and nitrogen emissions from human activities originate from agriculture.[8] Society must therefore tangibly reduce the loss of plant nutrients from agriculture in order to save our waters, on top of the significant measures already in place. Organic farms receive significant agri-environmental payments partly to improve water quality in seas, lakes and watercourses.[16] However, is there a scientific basis for this positive view of the benefits organic farming produces for water environments?

Plant nutrient loss from farmland

For many years our society has placed great hope in organic farming as a solution to problems related to plant nutrient leaching. In regard to nitrogen, several recent research projects, in Sweden and internationally, have shown that leaching of nitrogen is greater from organic systems than conventional under similar conditions.[1,7,13,14,17]

An important explanation of this is that using organic nitrogen fertilizer (manure, green manure and slaughterhouse waste) instead of mineral fertilizer gives rise to substantial nitrate leaching, a fact that has long been understood.[2] This is due to crops being less able to effectively utilize nitrogen in organic fertilizers as compared to mineral fertilizers. Because the nitrogen in the first case is largely bound organically (and is not soluble) it is not plant available. While mineral fertilizer is taken up by crops and microorganisms during the growing season, leaving minimal nitrogen residues in the soil to leach out, easily leached nitrogen is formed from organic fertilizers long after harvest. Nitrogen from organic fertilizers is released when the material is decomposed, a process that depends on soil moisture and temperature. This nitrogen can therefore become available after the crop is harvested, when it easily leaches out due to higher precipitation in autumn.

This basic process is the same for both conventional and organic farming, but is greater for the latter. This is because nutrient supply is provided primarily as manure, and green manure crops.[5, 6] Conventional farming supplements manure with mineral fertilizer that provides 70 per cent of the conventional crop's nitrogen requirements. Farmers using mineral fertilizer can easily control application of nitrogen to when it is most needed by the crop, significantly reducing the likelihood and amount of leaching. A Swedish field trial that measured leaching in both organic and conventional systems found, as would be expected, that nitrate leaching is greater from the organic systems and least from the conventional system that did not use manure (Table 11).[1,17]

Considering that yields are most often much lower in organic production, the loss per produced unit becomes significantly greater from these fields.[13] Moreover, when considering that as much food must be produced (on more acreage), this difference becomes very obvious. Total leaching for the same amount

TABLE 11. Nitrate leaching from organic and conventional farming systems without animals.[16] The figures shown are yearly averages from six-year crop rotations.

Yield and nitrate leaching	Organic	Conventional
Harvest (tonnes of dry substances per hectare)	2.0	6.1
Nitrogen levels in Leachate (milligrams nitrogen per litre)	12	7
Nitrate leaching (kilograms nitrogen per hectare)	34	25
Nitrate leaching per harvested unit (kilograms nitrogen per ton)	17	4.1
Nitrate leaching for the same yield as in conventional farming (kilograms nitrogen)	103.7	25

of food is therefore several times greater for organic than for conventional farming, as shown in long-term field trials. It is just this measure – the amount of leaching per product or per the same amount of product – that shows the real environmental impact from each type of cultivation system (Table 11).

Popular preconceptions are that soluble nitrogen applied using mineral fertilizer runs straight out through the soil and thereby contributes to eutrophication of our waters. This may occur in cases where the fertilizer applied substantially exceeds crop requirements, or in the rare years with heavy precipitation during spring planting. 1980 was just such a year. However, several trials have shown that if nitrogen application is done in quantities that correspond to the nitrogen requirements of the crop, then leaching is not greater than from unfertilized land (Figure 17).[3]

Further improvement is gained by dividing fertilizer application into smaller portions over the growing season, and thereby adapting fertilization to the needs of the crop for that particular season.[15] Several counter-measures are currently in use that re-

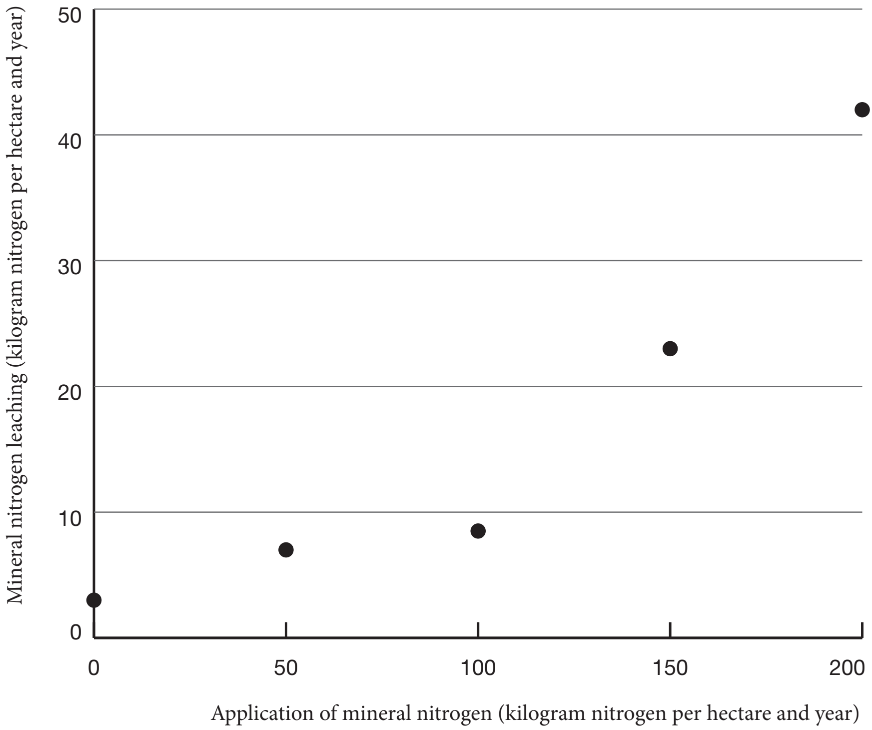


FIGURE 17. Leaching of mineral nitrogen after increasing amounts of mineral fertilizer in trials in western Sweden.[3] The figure clearly shows that fertilizer applications above standard recommendations (higher than approximately 80 kilograms of nitrogen) drastically increase leaching.

duce leaching, and which also receive agri-environmental payments. These includes catch crops in southern Sweden, and creating wetlands in agricultural landscapes. These measures have all been shown to be especially effective and not too costly.[4] An effective catch crop is ryegrass that can cut leaching losses of nitrogen by half from sandy soils in southern Sweden, with the related reduction of nitrate levels in water run-off (Figure 18).

In organic systems without animals, where no nitrogen fixing

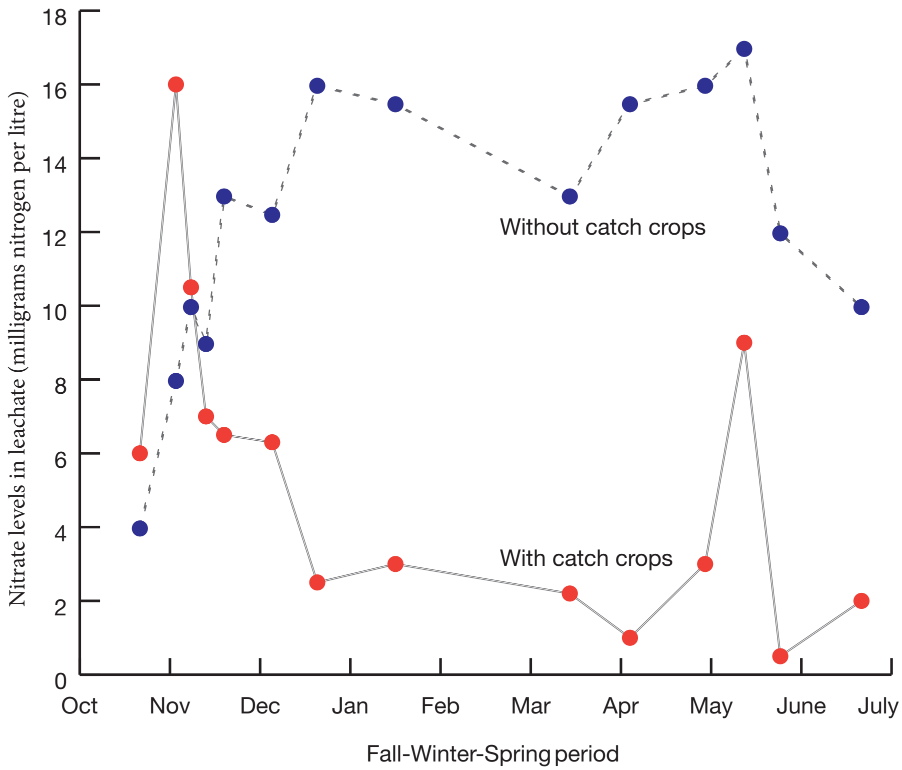


FIGURE 18. Nitrate nitrogen levels in leachate from sandy soils in southern Sweden with, and without, catch crops.[4] Catch crops are an example of an effective environmental measure for reducing nitrate leaching from fields.

forage grassland is grown, and no manure is used, nitrogen fixing green manure crops must be added to the crop rotation to supply other crops with nitrogen. Such crops are planted every third or fourth year, which means that these fields provide no yield during those years. Also, considering that years with no harvest further reduces total production over several years (in any crop rotation system), the nitrate leaching per product is even greater from organic cultivation systems that use green manure.

In relation to phosphorous, the nutrient most discussed in relation to eutrophication of our waters, there are no clear differences in its leaching when comparing organic and conventional farming methods calculated per hectare.[1,17]

However, since yields are about 50 per cent lower in organic production, the phosphorous loss per unit produced (or for the same amount of product) is greater from organic fields. As we state above, this measure correctly indicates environmental load (Table 11).

Using green manure crops in organic systems contributes to increasing the risk of phosphorous loss. This is because, in winter plant cells in green manure crops may freeze (as with forage). The destroyed cells release phosphorus, which can then run off when the weather warms. Scientific understanding of countermeasures against phosphorus loss does not match that of nitrogen. However, a range of studies designed to find effective methods to reduce phosphorous loss from farmed fields are currently underway. This provides reason to believe such countermeasures can be developed to reduce this issue to acceptable levels.

A final assessment of the previous Environmental and Rural Development Programme (LBU, 2006-2008) conducted by the Swedish University of Agricultural Sciences,16 found that directed problem-oriented agri-environmental payments (as for support for catch crops, buffer zones, and wetlands) provides better and more cost-effective results compared to general payments to entire cultivation systems (as with specific types of organic production). Programs intending to reduce nitrogen pay approximately SEK 1,500 to reduce leaching 1 kilogram per hectare and year through organic farming. However, producing the same effect using catch crops and wetlands costs on the order of SEK 100.

Future agriculture will combine the needs of production with full concern of the environment. New environmental measures are being tested and developed, and only measures with proven effects should receive government support.

Pesticides

As discussed previously, a further substantial difference between organic and conventional farming is the use of chemical pesticides. We noted that substances with pesticidal properties are also used in organic farming and that organic products may also contain residues of these pesticides.

Pesticides are used for problems on the fields with weeds, insect infestation, and various plant diseases. When pesticides end up beyond the field in rivers, lakes, or groundwater, they always carry a risk. This undesirable spread to the environment has been highlighted in many publications since the earliest use of pesticides in agriculture. Perhaps the best known example is Rachel Carson's *Silent Spring,* with her description of the negative effects of pesticides, primarily DDT and Lindan on insects and bird life.[9] The greatest risk for negative environmental effects arises when these pesticides are sprayed. Evaporation and wind drift cause the pesticides to spread from the fields whereby they enter nearby areas or waters. This can impact wild animals and birds by eradicating important food sources and insects. Point sources are another important source of the undesired spread of pesticides to the environment. These sources include spill onto forecourts or other hard surfaces when filling or cleaning sprayers.

Trials in southern Sweden have shown that addressing these point sources can significantly reduce concentrations of pesticides in nearby watercourses. This provides hope that reducing levels of such pesticides in our surface water is possible. In regard to the impact on ground water, more research is needed into how spraying and farming techniques can be changed.

However, most pesticides with undesired effects have been banned or removed from the market, and the likelihood is very small that new unsuitable pesticides can pass through the strict registration procedures imposed by the Swedish Chemicals Agency. Today's pesticides have been thoroughly tested in relation to their health effects and negative environmental impact both short and long-term, but this has not always been the case. And, despite the rigorous control procedures now in place to prevent health and environmental hazards, we can still find evidence of small amounts of pesticides in our food and soils, and in both surface and ground water. The levels found in Swedish surface and ground water are, however, so low (usually less than 1 microgram per litre - 0,000001 grams per litre, corresponding to a few drops in a large swimming pool) that negative effects on aquatic organisms are very rare. These are impacted significantly more by other environmental disturbances, such as eutrophication and clearing overgrown rivers. But of course, we must still use every possible means to prevent the release of pesticides outside farm fields into our waters.

> ***The greatest problem with pesticides is when they spread beyond farmed fields into adjacent ecosystems. These ecosystems are impacted negatively by these pesticides. Modern pesticides are manufactured to be more specific so their toxic effects are limited to the targeted organisms.***

Literature Chapter 6

1) Aronsson, H, Torstensson, G. & Bergström, L. (2007) Leaching and crop uptake of N, P, and K in a clay soil with organic and conventional cropping systems on a clay soil. *Soil Use and Management* 23, 71-81.

2) Bergström, L. (2003) Handelsgödsel är inte den stora boven (Chemical fertilizers are not to blame, Swedish only). I Johansson, B. (red.) *Formas fokuserar 1: Är eko reko?(Is eco OK?)* Formas, Stockholm, Sweden, p. 39-43.

3) Bergström, L. & Brink, N. (1986) Effects of differentiated applications of fertilizer N on leaching losses and distribution of inorganic N in the soil. *Plant and Soil* 93, 333-345.

4) Bergström, L.F. & Jokela, W.E. (2001) Ryegrass cover crop effects on nitrate leaching in spring barley fertilized with $^{15}NH\ ^{15}NO_3$. *Journal of Environmental Quality* 30, 1659-1667

5) Bergström, L., Bowman, B.T. & Sims, T. (2005) Definition of sustainable and non-sustainable issues in nutrient management of modern agriculture. *Soil Use and Management* 21, 76-81.

6) Bergström, L. & Goulding, K. (2005) Perspectives and challenges in the future use of plant nutrients in tilled and mixed agricultural systems. *Ambio* 34, 280-284.

7) Bergström, L., Kirchmann, H., Aronsson, H., Torstensson, G. & Mattsson, L. (2008) Use efficiency and leaching of nutrients in organic and conventional cropping systems in Sweden. I: Kirchmann, H. & Bergström, L. (red.). *Organic Farming – Ambitions and Limitations.* Springer, Dordrecht, Nederländerna, p. 143-161.

8) Brandt, M. & Ejhed, H. (2003) *TRK, Transport – Retention – Källfördelning. Belastning på havet (Loads on the ocean, Swedish only).* Swedish EPA Technical report 5247. Stockholm, Sweden, 120 p.

9) Carson, R. (1962) *Silent Spring.* Houghton Mifflin Company, Boston, USA, 400 p.

10) Geber, U. (2003) Ointressant ställa handelsgödsel mot stallgödsel (*Not necessary to compare chemical fertilizers with manure, Swedish only*). I Jakobsson, C. (red.) Formas fokuserar 1: Är eko reko?(Is eco OK?) Formas, Stockholm, Sweden, s. 43-47.

11) Granstedt, A. (2012) *Morgondagens jordbruk: med fokus på Östersjön (Tomorrow's agriculture: focusing on the Baltic Sea, Swedish only).* Södertörn University, Huddinge, Sweden, 135 s.

12) Koepf, H. (1973) Organic management reduces leaching of nitrate. *Biodynamics* 108, 20-30.

13) Korsaeth, A. (2008) Relations between nitrogen leaching and food productivity in organic and conventional cropping systems in a long-term field study. *Agriculture, Ecosystems and Environment* 127, 177-188.

14) Korsath, A. & Eltun, R. (2008) Synthesis of the Apelsvoll system experiment in Norway – nutrient balances, use efficiencies and leaching. I Kirchmann, H. & Bergström, L. (red.) *Organic Farming – Ambitions and Limitations.* Springer, Dordrecht, Nederländerna, p. 117-142.

15) Kätterer, T., Eckersten, H., Andrén, O. & Pettersson, R. (1997) Winter wheat biomass and nitrogen dynamics under different fertilizer and water regimes: application of a crop growth model. *Ecological Modelling* 102, 301-314

16) LBU (2009) *Slututvärdering av miljö- och landsbygdsprogrammet 2000–2006 – vad fick vi för pengarna?(Final evaluation of the Environmental and Rural Development Programme 2000-2006 - what did we get for our money? Swedish only)* Swedish University of Agricultural Sciences, Uppsala, Sweden, 470 p.

17) Torstensson, G., Aronsson, H. & Bergström, L. (2006) Nutrient use efficiencies and leaching of organic and conventional cropping systems in Sweden. *Agronomy Journal* 98, 603-615.

7

Is organic farming climate smart?

Here, we discuss greenhouse gases to identify the processes through which they are released to the environment and how farm management systems and fertilizer affect these emissions. To estimate greenhouse gas emissions from either organic or conventional production, the entire production chain in both must be considered. Comparing both types of farming to obtain an answer to the question of which is better from a climate perspective is complicated. Differing results can be obtained depending on the delimitations applied when comparing both systems. One determinative factor for the outcome of such estimates is changes in land use – that is, comparing the need with organic farming to use more farmland to produce the same amount of food to the possible conversion of available farmland to energy production since conventional farming provides adequate food production.

Greenhouse gases

Some 98 per cent of Sweden's greenhouse gas emissions are carbon dioxide, nitrous oxide, and methane. All three gases strongly impact the climate. Nitrous oxide and methane are usually measured in terms of carbon dioxide equivalents to facilitate comparison. This measures the climate impact of 1 kilogram of methane as corresponding to the impact of 25 kilograms of carbon dioxide. And 1 kilogram of nitrous oxide corresponds to 298 kilogram of carbon dioxide. These figures are based on the global warming potential these gases have over 100 years.[8]

Carbon dioxide represents nearly 80 per cent of total greenhouse gas emissions in the world, and for Sweden, too.[11] Carbon dioxide is primarily produced from our use of fossil fuels and from the biological decomposition of organic material.

Nitrous oxide represents 14 per cent of Swedish greenhouse gas emissions and is formed mostly in the ground, but also during storage and treatment of biological waste (mostly manure) and in various industrial incineration processes. Nitrous oxide is a gaseous nitrogen compound formed by the oxidation of ammonium to become nitrate (nitrification) and by the reduction of nitrate to nitrogen gas (denitrification) in the soil. Nitrous oxide is produced naturally in soil, as in unfertilized forest and pasture land. Since farmland is fertilized with nitrogen, larger amounts of nitrous oxide are formed there than in natural environments due to the nitrogen added to the system. Nitrous oxide emissions are difficult to measure due to significant variation in its release, so these emissions are usually estimated using emission factors where the rate of nitrogen transformed into nitrous oxide is estimated as an average. Swedish climate reporting assumes that a higher percentage of nitrous oxide is formed in organic fertilizer than from mineral nitrogen in the soil.[11,21]

There are several reasons why organic nitrogen fertilizer emits more nitrous oxide than mineral fertilizer. The fertilizer's organic material functions as a source of energy for micro-organisms, which increases their activity. This means that more nitrate is formed, with nitrous oxide as a bi-product. Oxygen consumption also increases with higher microbial activity, which easily causes oxygen shortages in the soil. This, in turn, leads to the reduction of nitrate (denitrification) and the formation of nitrous oxide. As well, plants absorb less of the nitrogen in organic fertilizer than they do from mineral fertilizer. The nitrogen remaining in the soil can lead to nitrous oxide emissions after harvest.

Methane represents the remaining 4 per cent of human-caused greenhouse gas emissions in Sweden and arises primarily through biological processes when organic material decomposes in anaerobic conditions, as in animals and humans during digestion, when storing manure, and in waste (landfills). Ruminants, especially cattle, produce larger amounts of methane in their digestion than other types of animals.[21] The formation of methane in animals can be controlled to some extent through their feed – less roughage and more fat in their rations can reduce the production of methane somewhat. As well, the animal's productivity affects their methane production. If this is lower (as is often the case in organic production), then methane formation per weight of product is greater.

To summarize, we can note that carbon dioxide and nitrous oxide from soils rich in organic matter, nitrous oxide from mineral fertilizer and manure, and methane from animal keeping comprise the greater share of greenhouse gas emissions from agriculture. The transport, processing, packaging, storage, and preparation of foodstuffs make up a smaller portion of emissions than does their production.[2] Mineral soils on farmland comprise a potential sink for greenhouse gases.[14]

The principle of soil organic carbon sequestration

Photosynthesis is the core process in which biomass is formed. During photosynthesis, plants take up carbon dioxide from the air and water, and nutrients from the soil to form carbohydrates using energy from the sun. Fixation of carbon dioxide in biomass reduces atmospheric levels, which is the primary way agriculture impacts the composition of air. More photosynthesis leads to greater production of biomass, whereby more of atmospheric carbon dioxide is transformed into biomass (Figure 19). All actions that increase crop production, such as applying nutrients and improving the supply of water, promote fixation of carbon

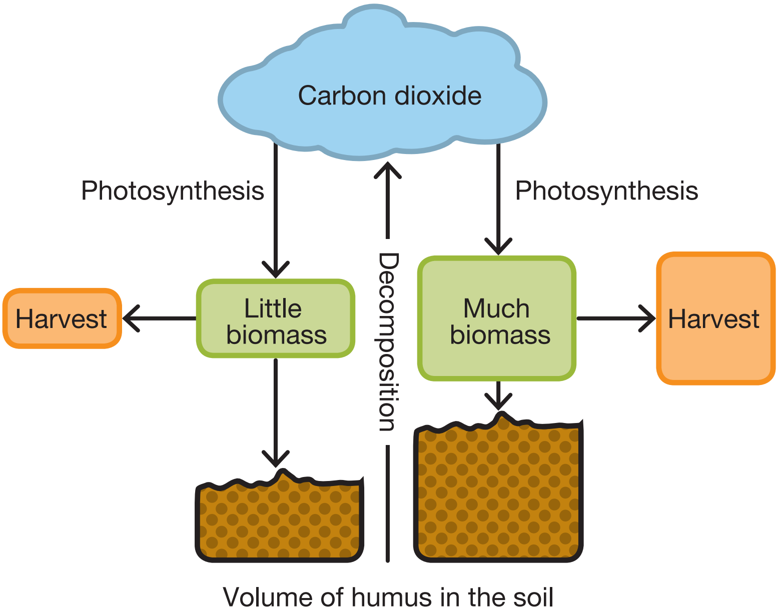


FIGURE 19. The volume of biomass produced determines how much humus can be formed in the soil.

dioxide. Larger production of biomass leads to more roots and plant residues after harvest. Soils are replenished with raw material for humus formation in this way, which increases the soil's humus content.

Plant residues remaining after harvest are decomposed, so only a portion is stabilized as humus in the soil where it remains for a longer time. Soil organic carbon sequestration occurs when the formation of humus is greater than the decomposition of existing humus. The amount of carbon held in soil as humus (which is approximately 50 per cent carbon) is more than double the amount of atmospheric carbon (as carbon dioxide). Changes to the humus content of soil therefore impact atmospheric carbon dioxide levels. This means there is significant potential to sequester carbon in farmlands as humus, and thereby reduce the amount of atmospheric carbon dioxide.

Soil organic carbon sorption is seen to have the greatest potential for reducing levels of atmospheric greenhouse gases.[25] Climate compensation is nearly always discussed in terms of greater biomass production, as by planting trees or converting farmland to permanent grasslands or forest. Other measures to reduce greenhouse gas emissions include more efficient recirculation of organic material and putting fields in green fallow. On the other hand, minimizing soil tillage has not been shown to be effective in this, considering the Swedish climate.

Carbon storage in soil for organic and conventional production

A strict comparison between organic and conventional production must be based on the same type of production. This avoids incorrect comparisons of different types of farming. Modern organic farming in Sweden is primarily directed toward dairy and meat production, whereby a large share of crops in the rotation involves forage.

Forage consists of perennial plants (usually grass and clover) which fix a large share of carbon in their root systems through photosynthesis. As well, perennial plants grow throughout the growing season. This long growing season means that the forage evaporates more water, and that it protects the ground from direct solar radiation. Soil under forage is therefore usually dryer and colder than with a spring-seeded annual crop (such as wheat) causing slower decomposition of organic material. Forage crops are therefore known to improve the carbon balance in soil,[3] which has led to the perception that organic production should result in higher concentrations of carbon in soil.[13] If, on the other hand, we compare organic to conventional farms with the same type of operation (dairy and meat production), this leads to a different conclusion. Carbon storage in conventionally farmed forage is similar to that in organically farmed forage crops, but again, conventionally farmed produce higher yields of other crops included in the rotation, leading to greater total storage of carbon in the soil.

Long-term field trials around the globe show that the levels of carbon in organic systems can be higher than in corresponding conventional systems.[7] Which is the opposite of the expected. Since crop production is lower in organic farming, which implies lower inputs of organic material to the soil (as roots and crop residues), the carbon levels in these soils should not be higher than for conventional farming (for the same type of operation).

Nevertheless, it was found that carbon levels increased in organically farmed soils but not in those farmed conventionally.[1,16] A thorough review of each trial included for this showed that when the carbon level was higher in organic farmed soils, more organic fertilizer was applied.[18] This additional supply, which was not provided in the conventional systems, could explain the higher carbon levels in these organic farms.

In strict scientific comparison, appropriate system boundaries should be considered. The added application of external resources to one system, but not the other, gives rise to incorrect interpretations. A transfer of plant nutrient products by way of the organic fertilizer from conventional to organic farms is, as we have noted, a common farming practice (Chapter 5), but this makes strict scientific comparison impossible.[20]

When organic trials involving this disproportionally large application of organic fertilizer were removed from the above comparison, it was found that the claim that organic farming increases soil humus content could not be confirmed.[16] In the studies where crop rotations were compared between the systems (with no added application of manure), no additional carbon storage was found in the organic farms.[17]

Reducing atmospheric carbon dioxide levels and sequestering carbon in soils is possible by increasing photosynthesis. This means that all measures taken

to increase biomass production (higher yields, permanent vegetation) will also store more carbon in the soil and increase its humus content. Therefore, measures that promote crop production – as with nitrogen fertilization – also have a positive effect on carbon levels in the soil.

Carbon storage in soil with and without nitrogen fertilization

An important question involves the role fertilization with mineral nitrogen has in affecting carbon storage in soils. Some researchers claim that fertilization with mineral nitrogen leads to a reduction of carbon levels in soils.[12,19] Their reasoning is based on long-term trials where the carbon levels in nitrogen fertilized trial plots has declined over time while trial plots fertilized with manure show no decline in carbon levels.

The decline in amounts of carbon after nitrogen fertilization is due to the soil having high carbon levels prior to the trials starting (as determined by previous land use). Most often, examples where the carbon levels in soil decline are when a perennial grassland (which has high carbon levels) is ploughed to grow annual crops.[14] The mass of roots and crop residues added to soil through farming annual crops is significantly lower than the mass added in grasslands with permanent vegetation cover, hence the declining carbon levels when growing annual crops only.

Findings from unfertilized treatments can help in clarifying this issue.[22] Carbon levels decline most in farming systems that do not use fertiliser. This is explained by the fact that in farming without fertilizer, the much lower yields result in less raw material for humus formation. Nitrogen fertilization limits this decline as compared to an unfertilized control, and carbon levels remain higher than without fertilization.[23] That carbon levels in the soil can still decline in certain situations even with nitrogen fertiliza-

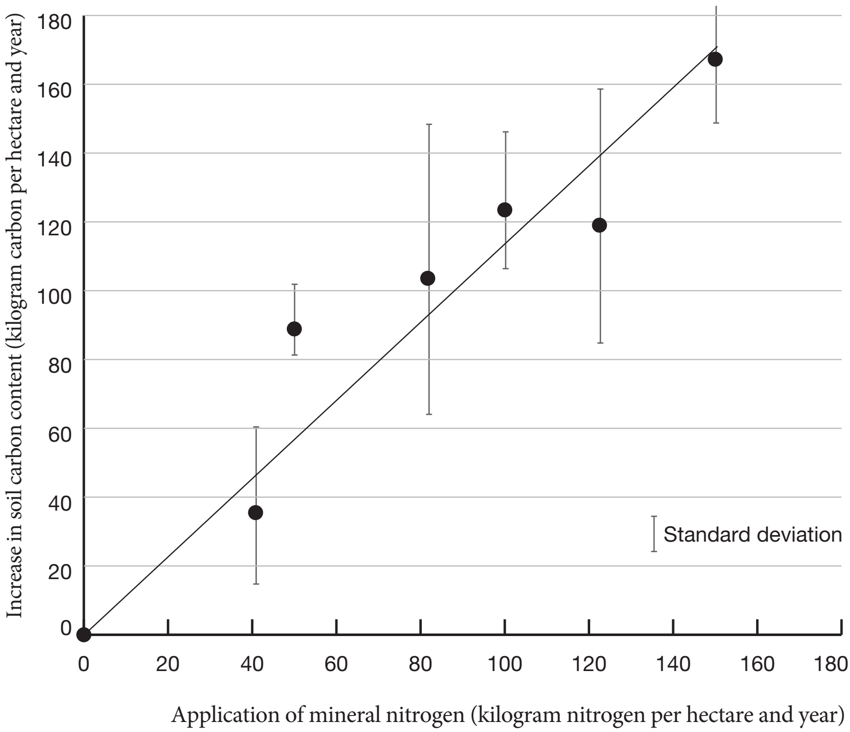


FIGURE 20. Increase in soil organic carbon content due to nitrogen fertilization, data from long-term field trails.[14]

tion is not due to the nitrogen fertilization, but rather to the fact that the addition of carbon by way of plant biomass is not as great as under the previous land use. This happens, for example, when converting from forage to cereal crops or in farming on naturally humus-rich soils.

The application of manure adds humus to the soil. The volume added determines the extent of the change in the soil's carbon levels in a field. In field trials, the volume of added manure can be very high, whereby the carbon level in the soil is increased. In actual farming situations, though, the volume of manure that can be added is determined by how many animals are kept on the farm or nearby. Carbon levels will therefore increase or decrease depending on the starting conditions for these trials as well as the amount of manure added. How the manure is spread can affect carbon levels in individual fields but still not affect the carbon balance in the region. Results from many long-term field experiments have shown that increased production of biomass has the greatest potential to bind more carbon and thereby increase the carbon store in soil.[14] Higher production of biomass due to increased nitrogen fertilization leads to an increase in soil carbon levels. (Figure 20) The correlation between nitrogen fertilization and carbon storage shows that 1 kilogram of nitrogen increases soil carbon stocks on average by 1 kilogram. These data are from Swedish trials that have been conducted for 50 years or longer, which have also been confirmed in other long-term field trials.[15]

Emission of greenhouse gases from cultivation systems can be estimated in different ways:

- Per areal unit or added amount of nitrogen.
- Per amount of produced product (including yield).
- Per equal amounts of produced product (including yield and requirements per areal unit).

A scientifically relevant comparison presumes that the same amount of food is produced. This requires considering the added areal unit necessary to compensate for lower production, as well as possible alternative uses of land taken out of food production.

Greenhouse gas emissions with mineral nitrogen fertilization compared to green manure nitrogen

Nitrogen is the most important nutrient for yield formation, but is also central to the emission of greenhouse gases. Therefore, a key question asked by many is whether fertilization with mineral

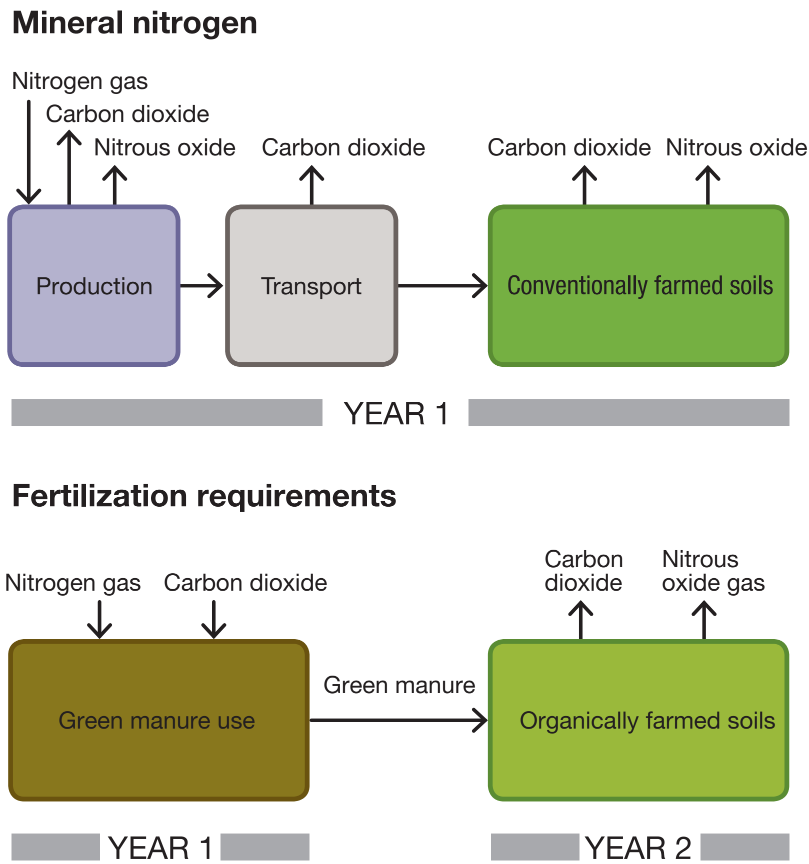


FIGURE 21. Flows of gases in the production and use of mineral nitrogen compared to application of nitrogen by way of green manure crops. Green manure crops also mean an entire season without productive yield.

nitrogen has a positive or negative effect on greenhouse gas emissions. Does growing legumes, binding atmospheric nitrogen in symbiosis with bacteria in their roots, give rise to less greenhouse gas emissions than the chemical fixation of nitrogen from fertilizer production and the use of mineral nitrogen?

A common perception is that greenhouse gas emissions are greater when mineral nitrogen is used than in growing legumes as green manure or forage. Manufacturing mineral nitrogen fertilizer is an energy intensive process. This transforms nitrogen gas from the air, under high pressure and temperature, into ammonium using hydrogen gas. Currently this hydrogen is produced from natural gas. When manufacturing mineral nitrogen, carbon dioxide is formed during both production of hydrogen, and the synthesis of ammonium.[27] In addition, there are emissions of carbon during the transport of the fertilizer from factory to field.[27] Finally, on the farm, greenhouse gases are both emitted and captured (Figure 21). Including both the emission of greenhouse gases and soil carbon sequestration, results in a negative balance where the net emission is 1.7 kilograms of carbon dioxide equivalents per kilogram of mineral nitrogen produced.

The emission and capture of greenhouse gases in biological nitrogen fixation by legumes can be estimated in a similar way. Clover, for example, can be grown as green manure crop to provide nitrogen (after being ploughed down) in the first year in a crop rotation for the crop grown in the second year of the rotation (Figure 21). As the legumes grow, biological nitrogen fixation does not give rise to larger emissions of greenhouse gases than for unfertilized land.[10] But when the green manure decomposes, nitrous oxide is released. Ammonia, that may also be released from decomposition of nitrous-rich plant residues, and greater nitrate leaching from ploughing down green manure indirectly contributes to greenhouse gas emissions since a portion of the ammonium and nitrates are transformed into nitrous oxide. Green manure has a nitrogen impact on the next year's crop – raising its yield. In this way, green manure crops give rise to soil organic carbon sequestration. As well, the addition of green manure increases the inputs of organic material to the soil, which leads to humus formation and carbon sequestration. In total, green manure crops do not cause net emissions of greenhouse gases, despite the greater loss of nitrous oxide. The balance is positive, so 2.5 kilograms of carbon dioxide equivalents per kilogram of nitrogen can be captured by green manure.

This would seem to be a clear comparison – mineral nitrogen produces emissions and green manure leads to capture of greenhouse gases, when calculating the amount of nitrogen added or per kilogram of yield. The lower emission per mass of nitrogen or product in organic farming compared to conventional has at times been interpreted as evidence that organic farming is more climate smart. However, expressing greenhouse gas emissions per kilogram of product[11,26] does not consider the substantial differences in yields. Yields are lower when using green manure than when using mineral nitrogen despite the relatively large amounts of nitrogen added by the green manure (up to 500 kilograms of nitrogen per hectare and year).[5]

The same yield from organic farming requires an increase in farmed area, which leads to substantial greenhouse gas emissions.

As we noted previously, more farmland is needed when using green manure to obtain equal amounts of product. The added area necessary to compensate for lower yields must be included in the calculation to determine total emissions in the green manure alternative. Using this added area for farming involves a significant change in type of land use. This means using grassland, forest and natural lands for farming. Farming increases the decomposition of previously captured carbon, and reduces the soil's store of carbon. Less biomass is added (due to harvesting), resulting in less carbon input to soil. Farming land that was previously under permanent vegetation gives rise to substantial greenhouse gas emissions. The added loss of greenhouse gases will then continue until the levels of humus have stabilized at a lower level.

Calculations that include changes in land use are complex. This demands comparable conditions and well-defined pre-conditions. Therefore, comparing the changes to land use is necessary to establish full understanding of the greenhouse gas emissions is-

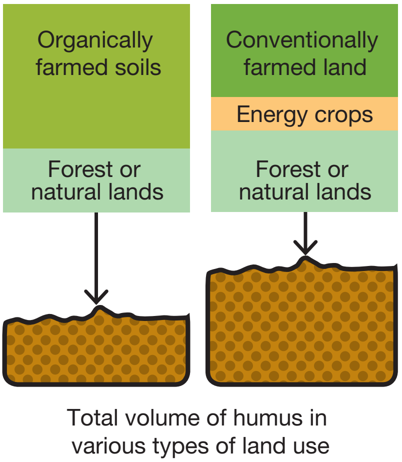


FIGURE 22. Higher yields from conventional farming require less acreage to produce the same amount of food than in organic farming. The change in land use impacts the volume of humus in the soil. Forest and natural lands have a greater capacity to fix carbon dioxide as humus, and the humus levels are higher in conventional production.

sue. When several hundred or thousands of carbon dioxide equivalents per hectare are emitted from the added farmland area every year, the positive balance for green manure crops is reversed. Examples of calculations for greenhouse gases from extensively and intensively farmed land, respectively, show that emissions are much higher for extensive production simply due to the greater area of farmland required.[4]

Figure 22 illustrates an example of how existing acreage can be used for various production purposes in both organic and conventional farming. More acreage is needed for organic farming due to lower yields, thereby reducing the acreage available for forest or natural lands. The lower demand for farmland in conventional production enables growing energy producing crops on the remaining acreage. This can then be used to replace fossil fuels to reduce greenhouse emissions.

Greenhouse gas emission from manure

Nitrogen in manure is recirculated nitrogen originating from harvest products used as feed. Emission data show that fermentation in ruminants gives rise to significant emissions of methane, and methane is also produced when manure is stored.[21] After the manure is applied to soil, nitrous oxide is released.

However, manure also raises yields (proportionally to the content of mineral nitrogen in the manure), which increases carbon levels in the soil. As well, the manure adds organic carbon, of which approximately one-fourth is stabilized in soil as humus. But the greenhouse gas balance turns deeply negative due to emissions of methane and nitrous oxide, despite the positive effect of manure on the carbon balance in the soil. Emissions of nitrogen from manure can be compared to those from mineral nitrogen in Sweden. Dividing all available manure by total farmland area in Sweden, corresponds to a dose of approximately 40 kilograms of nitrogen per hectare and year. The average dose of mineral nitrogen for Swedish cropland is 80 kilograms of nitrogen per hectare and year. This means that the nitrogen emission from 40 kilograms of manure corresponds to 600 kilograms of carbon dioxide equivalents, and to 136 kilograms of carbon dioxide equivalents for 80 kilograms of mineral nitrogen. Nitrogen from manure thereby causes greater greenhouse gas emissions than mineral fertilizer.

A reasonable conclusion

A report on the climate impact of organic farming stated that "a consumer today generally should choose organic food for other reasons than a desire to reduce their climate impact."[24] Our calculations indicate the same finding. The indirect effect of needing to increase farmed acreage to obtain the same amount of food from organic farming causes substantial greenhouse gas emissions. An overall assessment shows that conventional agriculture is more climate smart than organic.

Literature Chapter 7

1) Andrén, O., Kätterer, T. & Kirchmann, H. (2008) How will conversion to organic cereal production affect carbon stocks in Swedish agricultural soils? I Kirchmann, H. & Bergström, L. (red.) *Organic Crop Produc-tionOrganic Farming – Ambitions and Limitations.* Springer, Dordrecht, Holland, p. 161-172.

2) Angervall, T., Sonesson, U., Ziegler, F. & Cederberg, C. (2008) *Mat och klimat(Food and Climate). En sammanfattning om matens klimatpåverkan i ett livscykelper- spektiv (A summary of the climate impact of food using a lifecycle perspective, Swedish only)*. SIK Institute for Food and Biotechnology AB SIK-rapport (Report) No. 776 2008. Gothenburg, Sweden, 12 p.

3) Bolinder, M.A., Kätterer, T., Andrén, O., Ericson L., Parent, L-E. & Kirchmann, H. (2010) Long-term soil organic carbon and nitrogen dynamics in forage-based crop rotations in Northern Sweden (6364 N). *Agriculture, Ecosystems and Environment* 138, 335-342.

4) Burney, J.A., Davis, S.J. &. Lobell, D.B (2010) Greenhouse gas mitigation by agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America* 107, 12052–12057.

5) Dahlin, S. & Stenberg, M. (2010) Cutting regime affects the amount and allocation of symbiotically fixed N in green manure leys. *Plant and Soil* 331, 401-412.

6) Flessa, H., Ruser, R., Dörsch, P., Kamp, T., Jimenez, M.A., Munch, J.C. & Beese, F. (2002) Integrated evaluation of greenhouse gas emissions (CO_2, CH_4, N_2O) from two farming systems in southern Germany. *Agriculture, Ecosystems and Environment* 91, 175-189.

7) Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., Mäder, P., Stolze, M., Smith, P., El-Hage Scialabbad, N. & Niggli, U. (2012) Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences of the United States of America* 109, 18226-18231.

8) IPCC (2007) *Working Group I Fourth Assessment Report "The Physical Science Basis", Chap. 2*. https://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/ar4-wg1-chapter2.pdf

9) IPCC (2006) *IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use.* http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

10) Jensen, E.S., Peoples, M.B., Boddey, R.M., Gresshoff, P.M., Hauggaard- Nielsen, H., Alves, B.J.R. & Morrison, M.J. (2012) Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. *Agronomy for Sustainable Development* 32, 329–364.

11) Swedish Board of Agriculture (2012) *Ett klimatvänligt jordbruk 2050 (A climate friendly agriculture in 2050, Swedish only)*. Rapport 2012:35 (Report). Jönköping, Sweden, 117 p.

12) Khan, S. A., Mulvaney, R. L., Ellsworth, T. R. & Boast C. W. (2007) The myth of nitrogen fertilization for soil carbon sequestration. *Journal of Environmental Quality* 36, 1821–1832.

13) Kätterer T., Bolinder M.A., Andrén O., Kirchmann H. & Menichetti L. (2011) Roots contribute more to refractory soil organic matter than aboveground crop residues as revealed by a long-term field experiment. *Agriculture, Ecosystems and Environment* 141, 184-192.

14) Kätterer, T., Bolinder, M. A., Berglund, K. & Kirchmann, H. (2012) Strate- gies for carbon sequestration in agricultural soils in northern Europe. *Acta Agriculturae Scandinavica*, *Animal Science Section A* 62, 181–198.

15) Körschens, M., Albert, E., Armbruster, M., Barkusky, D., Baumecker, M., Behle-Schalk, L., Bischoff, R.,Čergan, Z., Ellmer, F., Herbst, F., Hoffmann, S., Hofmann, B., Kismanyoky, T., Kubat, J., Kunzova, E., Lopez-Fando, C., Merbach, I., Merbach, W., Pardor, M.T., Rogasik, J., Rühlmann, J., Spiegel, H., Schulz, E., Tajnsek, A., Toth, Z., Wegener, H. & Zorno, W. (2013) Effect of mineral and organic fertilization on crop yield, nitrogen uptake, carbon and nitrogen balances, as well as soil organic carbon content and dynamics: results from 20 European long-term field experiments of the twenty-first century. *Archives of Agronomy and Soil Science* 59, 1017–1040.

16) Leifeld, J. & Fuhrer, J. (2010) Organic farming and soil carbon sequestra- tion: what do we really know about the benefits? *Ambio* 39, 585–599.

17) Leifeld, J. (2012) How sustainable is organic farming? *Agriculture, Ecosystems and Environment,* 150, 121–122.

18) Leifeld, J., Angers, D.A., Chenu, C., Fuhrer, J., Kätterer, T. & Powlson, D.S. (2013) Organic farming gives no climate change benefit through soil carbon sequestration. *Proceedings of the National Academy of Sciences of the United States of America* 110, E984.

19) Mulvaney, R. L., Khan, S. A. & Ellsworth, T. R. (2009) Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production. *Journal of Environmental Quality* 38, 2295-2314.

20) Nowak, B., Nesme, T., David, C. & Pellerin, S. (2013) To what extent does organic farming rely on nutrient inflows from conventional farming? *Open Access, IOP Publishing, Environmental Research Letter* 8, 044045.

21) Naturvårdsverket (2013) *National Inventory Report Sweden 2013*. Stockholm, Sweden, 423 p. http://www.naturvardsverket.se/upload/sa-mar-miljon/statistik-a-till-o/vaxthusgaser/2013/NIR_SE_Submission_2013_Report_15_mar.pdf

22) Powlson, D.S., Jenkinson, D.S., Johnston, A.E., Poulton, P.R., Glendining, M. J. & Goulding, K.W.T. (2009) Comments on "Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production", by R.L. Mulvaney, S.A. Khan, and T.R. Ellsworth in the Journal of Environmental Quality 2009 38:2295–2314. *Journal of Environmental Quality* 39, 749-752.

23) Powlson, D. S., Whitmore, A. P. & Goulding, K. W. T. (2011) Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science* 62, 42–55.

24) Röös, E., Sundberg, C., Salomon, E. & Wivstad, M. (2013) *Ekologisk produktion och klimatpåverkan (Organic production and climate impact, Swedish only)*. Swedish University of Agricultural Sciences, EPOK – Centre for Organic Food and Farming, Uppsala, Sweden, 72 p. http://www.slu.se/Documents/externwebben/centrumbildningar-projekt/epok/Publikationer/Eko-prod-o-klimatp-webb.pdf

25) Smith, P. (2012) Agricultural greenhouse gas mitigation potential globally, in Europe and in the UK: What have we learnt in the last 20 years? *Global Change Biology* 18, 3543.

26) Weiske, A., Vabitsch, A., Olesen, J.E., Schelde, K., Michel, J., Friedrich, R. & Kaltschmitt, M. (2006) Mitigation of greenhouse gas emissions in European conventional and organic dairy farming. *Agriculture, Ecosystems and Environment,* 112, 221-232.

27) Yara (2013) Garanti klimatavtryck. Yara International, Oslo, Norway. http://www.yara.se/sustainability/climate/guarantee/index.aspx, Swedish only

8

Organic farming in practice

At first, so-called alternative farming primarily attracted idealists who had a specific interest in 'natural' production. Into the 1980s, therefore, no more than 1 to 2 per cent of all Swedish arable acreage was under organic cultivation. Organic farming has since increased steadily to now cover 15 per cent of total arable acreage and 23 per cent of all pasturage.[11] The total amount of farmed acreage converted to organic production by 2013 was 460,300 hectares (acreage covered by governmental agri-environmental payments), of which 77 per cent were KRAV certified. The government set a target to have certified organic farming on 20 per cent of Sweden's arable land by 2010. This target was not reached despite heavy subsidies totalling more than SEK 500 million annually for this type of farming through government funding of various agri-environmental payments.[6] We therefore discuss the characteristics of organic farming in Sweden here.

National economic subsidies for organic farming

Organic production in Sweden has received specific national governmental subsidies since 1989, intended to promote this type of agriculture. These national subsidies make it economically advantageous for many farmers to convert to this type of production, even though they may not necessarily agree or sympathize with its basic ideological concepts. Lower production from organic farming earns less income that is compensated for by higher prices of these products, and by the government subsidy. Because of these national subsidies, organic farming has become a significant industry in society where every link in the supply chain – from farmer, to certification body (KRAV), to the processing industry and grocery stores – has an economic interest in promoting these products. Reducing or eliminating these government subsidy programmes is therefore very difficult politically.

Dairy and beef production dominate

Nearly two thirds (64 per cent) of the certified organic arable acreage is used for ley and green feed growing, crops used as roughage in dairy and beef production.[12] This is also confirmed in statistics for organically certified livestock farming in 2012. These show that cattle (47,600 dairy cattle, and 63,900 suckler cows, or approximately 100,000 animal units) make up the largest portion, while 49,700 pigs (corresponding to some 5,000 animal units) and 946,000 poultry (corresponding to 9,000 animal units) together are a much smaller portion.[10,11]Dairy and beef cattle farms, both organic and conventional, are located primarily in forest and central districts. Cereal production is most prevalent in the plains districts with larger continuous fields, and here, there are few organic farms. For example, 24 per cent of the acreage in Jämtland County (in mountainous Northern Sweden) is farmed organically, while only 4 per cent of the cultivated acreage in the flatlands of the Skåne region in Sweden's far south.

That meat and dairy farms – where cattle convert forage into the final product – are the type of farmsconverted to organic production is explained by the fact that grassland, especially when dominated by leguminous plants, provide larger harvests without the need to add nitrogen fertilizer. Plant protection products are not needed. But, this also holds for conventional grassland production, as it is relatively easy to keep weeds in check. Requirements to eliminate use of mineral fertilizer and chemical pesticides can therefore be easily met for dairy and beef production, and many farmers had already reduced their use of manufactured products prior to conversion. Thus, conversion brings relatively small changes. Moreover, natural pasture land makes up nearly double the share of organically farmed acreage as compared to conventional. Often, these fields cannot be used for growing crops since they have uneven terrain, large stones, trees, and similar. In any case, before conversion to organic farming, these fields were not fertilized or spayed with plant protection agents.

Many people may associate organic dairy and beef production with small idealistic conditions. Again, this is not the case in Sweden. Organic dairy farms are nearly as large, in terms of acreage and number of animals, as conventional farms. Statistics from the Swedish Board of Agriculture show that 52 per cent organic, and 49 per cent of conventional dairy cow herds in 2011 had over 200 cows.[10] Modern equipment, such as for robotic milking, is used in exactly the same way for both conventional and organic cow herds. A necessity to obtain acceptable milk yields from organic farms is that pasture and forage production is high and nutritious. Just as with conventionally kept dairy cows, cows in organic production are therefore grazed on fully arable land rather than semi-natural pasture.

On the other hand, pig and poultry producers generally show less interest in organic production, for several reasons. First, these animals eat cereals; and grain harvests are much smaller in organic production. Without grassland in the crop rotation, it is much more difficult to control weeds and disease. The requirement that these animals should be raised outdoors for longer periods of the year also leads to lower production, and involves more work. All of which lead these farmers to hesitate when considering conversion.

As previously stated, conversion to organic farming involves a significant change in the choice of crops. Available statistics show that acreage under demanding crops, such as potatoes, oil seeds, and sugar beets, declines with conversion to organic production.[12]

Conventional animal keeping and organic plant production on the same farm

Conventional and organic production of the same crop or the same type of animal on the same farm is not permitted under KRAV rules. On the other hand, it is permitted to run organic crop production while keeping livestock conventionally on the same farm – a significant advantage for organic farming. These farmers can use manure from their conventional livestock production in their organic crop production. This way, conventionally farmed fodder becomes a source of plant nutrients in organic farming, as we noted in Chapter 5. This is not entirely compatible with the basic philosophy of organic farming – to be self-sufficient units. Rather, conventionally produced plant nutrients are used to increase yields of organically grown crops.

Biodiversity

Farmland is, indeed, intended for the culture of specific crops. Biodiversity on these fields, in the form of weeds within the plant stock, is not desired in either organic or conventional production. The purpose of chemical or mechanical weed control is precisely the same – to reduce the amount of weeds that would otherwise act as hosts for insects. Conventional farming is, however, significantly more efficient at controlling weeds, and therefore organically farmed fields have more weeds, which does increase biodiversity. Likewise, chemical control of pests in conventional farming can impact other species than those intended to be controlled. In this way, biodiversity is usually greater on organic fields than conventional.

But the degree to which organic farming promotes biodiversity depends on additional factors[1,2] and also on which organisms and spatial scale are included in the analysis. The more bio-diverse lands and environments are those found away from farmed fields. Therefore, a basic issue is how farming activities impact diversity elsewhere than on the farmed fields. Diversity of organisms in farming landscapes is greatest on permanent pasture land, and in 'islands', such as non-arable outcrops, ditches, hedges, and similar, where various organisms can find their niche. For some organisms, it is also important to have transport routes between their nesting sites and food. There are several strategies used in conventional farming to promote diversity in farm landscapes,such as: creating skylark plots (small areas in fields left unseeded where skylarks can nest and feed); maintaining edge zones around fields where pesticides may not be used (which then qualifies for certain agri-environmental payments[6]); and growing special crops on a farm's land in order to increase the amount of food for pollinators and for insectivorous and seed-eating birds.[7] Public funds currently used to promote organic farming, could instead be used to further stimulate such targeted conservation measures. This would most likely provide greater benefit to biodiversity in farming landscapes than general subsidies for organic farming.

Biodiversity is generally greater on organic farms.[1] According to one meta-analysis of scientific studies, species richness is approximately 30 per cent higher on organic farms compared to conventional.[13] The effect was greater in plains districts with a higher percentage of farmed fields than in forest districts which have a lower share of farmed fields. A varied, small scale landscape structure with forest, pasture, and farmed fields benefits biodiversity due to the presence of pasture land, non-arable outcrops, edge zones, stone walls, stone piles, tree-lined avenues, hedges, trees, ditches, ponds, and wetlands.[1,2] The greatest species richness is found in natural pasture lands, which are often herbaceous, and are valuable biotopes for insects and animals higher in the food chain. Organic farms generally have a greater share of pasture land, which therefore partially explains their higher average biodiversity. In short, the variation in the farm landscape, and the share of pasture on the farm, have a greater impact on biodiversity than does any difference in whether the fields are organically or conventionally farmed.[5]

An often overlooked indirect effect on biodiversity in organic farms is their lower crop yields. It should be noted again that significantly larger acreage is required to enable producing an equal amount of food in organic farming as compared to conventional production (see Chapter 3). As long as we rely on our food being produced elsewhere in the world, this loss of production in Sweden will not lead to lower biodiversity. If the amount of farmed acreage in Sweden must be increased, there are recently abandoned agricultural fields to take back into production,and after that, there are forest lands and perhaps even species-rich pasture lands to be farmed. However, our imports of foodstuffs and fodder is more likely to increase further, leading to changes in land use elsewhere in the world. Comparison between the two types of systems at the field, landscape, and global levels may show differing findings.

Weeds are a significant problem

Weed problems are not only seen in organic farming field trials, they are a known problem in all practical farming.[3] On conversion to organic farming, weeds are often a negligible problem due to the conventional control methods previously used. However, after a few years of grain crop rotation, weed prevalence increases. A similar situation is wide-spread in Europe, and moreover, these problems tend to increase over time. Certain years, the amount of weeds can be so great that farmers chose not to harvest the field. The uncontrolled spread of weeds in organic farming is its Achilles heel. For this reason, some organic farmers return to conventional farming entirely when their weed problems become too severe.

In organic dairy and beef production, which is based on forage crops, weeds can most often be kept under reasonable control. An exception is dockweed (*Rumex*), which can quickly proliferate on organic farms farming primarily forage.

Conventional farming increasingly uses no-till seeding for several crops, which requires chemical weed control. The method primarily used in organic farming is mechanical weed control,[3] where weed infested fields are ploughed down before seeding. Fields can also be harrowed, which is often done in turns. When the weed problem becomes too great, the field is put in fallow and harrowed intensively for an entire growing season. This uses significant amounts of energy, with related greenhouse gas emissions, and also means farmers 'lose' a year of harvest. Mechanical weed control methods require significantly more energy than chemical control, and are not very effective in crop rotations that do not include leys.

One control method available in fields where weeds have taken over, and which is also commonly used, is to return to conventional production for a few years. Then, chemical pesticides are used in order to reduce hard to control weeds. Subsequently, the farmer re-converts to organic production, and after a qualifying year, crops can once again be sold as organic, to once again receive agri-environmental payments. This demonstrates further how organic farming can be dependent on conventional methods.

Shortage of seed

The EU Regulation on the Production & Labelling of Organic Products (as amended) requires that seed shall be produced organically, and that the recognised control authority in each Member State (the Swedish Board of Agriculture) has the right to issue exceptions from this requirement.[4] For the organic farmer, strong and viable seeds are especially important as their ability to control disease later in the growing season is limited. In reality, the requirement of organically produced seeds limits the choice of variety for the organic farmer. Moreover, the availability of organically produced seed has been insufficient for many years, and what is available may be low quality in regard to germination capacity and seed-borne infection. This has led the Swedish Board of Agriculture to issue exemptions allowing the use of conventionally produced seed. Such exemptions enable many to wait with their seed purchase until the organic varieties run out. Still another example of how, in practice, organic farmers can improve their production prerequisites by using loopholes in their own regulatory framework, and to rely on conventional production.

Poor yield stability

Yields will always vary from year to year, but conventional agriculture provides the better prerequisites for less fluctuation. This is due to several factors, including: seed quality, access to mineral fertilizers, and more effective pesticides when needed. All contribute to increasing yield stability. Since organic farming excludes these production aids, using less effective alternatives instead, assuring yield stability is generally more difficult.[14]

Sensitive crops, like potatoes and planted cucumber, where the early emergence of mildew can ruin an entire crop in any given year, illustrates the problem. All the work and energy invested in production is then wasted entirely. Similarly, serious insect infestation in oil crops in any given year has substantial negative impact. Interviews with produce farmers highlight that limitations in controlling weeds and pests are seen as serious threats to yield stability – and thereby profitability.[8] Low seed quality is also given as the primary reason why few produce farmers consider converting to organic systems. The poor yield stability is one more reason why most organic farmers are dairy and meat producers. Assuring yield stability in forage crops is significantly less complicated.

Looking forward

A viewpoint often argued is that organic cultivation is the leading edge of agriculture, and will become the dominant system. Many feel that something as basic as the production of food must be done using 'natural' means and methods. These proponents believe that natural production should be self-evident and therefore all farming should be organic in the future.

Current research findings, however, show that promised advantages of organic farming have not been achievable, which raises the question of whether these are possible at all. Can organically produced yields be significantly increased? Can a functioning plant nutrient ecocycle be achieved? Can organic fertilizer be used more effectively? Will biological pest control be as effective as pesticides? Can leaching of plant nutrients be reduced? Will organic pork and poultry production become more common? Will this increase biodiversity in agricultural landscapes?

Many methods, practices, and rules are applied to both conventional and organic farming, which means that both are benefited by more research and understanding regardless whether this was driven by the one system or the other. Examples of these include research into improving and developing tillage methods, continued plant breeding for better crops, systematic practice of beneficial crop rotation, and growing more crops in a single season – all of which benefit both organic and conventional farming.

Still, holding to the principle of using only 'natural' fertilizer for crop production will mean that organic farming remains extensive, since natural means will remain a limited resource, in the future as it is today, and has been historically. As organic farming becomes more prevalent, there will be less nutrients available to transfer from conventional systems to organic in the form of residuals. This means that organic yields will remain lower, even in the future. The prevalent view in organic farming is that 'nature makes it best,' which is why only natural means and methods are used in production. The basic view in society, generally, is rather that 'nature makes it good, but humans can make it better.'

Think of this analogy. 'Natural' medicine advocates using only natural preparations, while medical science uses both synthetic and natural pharmaceutical substances to cure disease. In the same way, the 'natural' approach of organic systems limits crop production and the efficient use of nature.

Political demands to further increase acreage under organic culture and increase public procurement of organic food may seem ambitious and forward looking. But the combined experience of scientific research indicates that the future of sustainable agriculture is based on new ideas, discoveries, innovative and improved technical equipment, and above all, fully considering all our environmental prerequisites.

Literature Chapter 8

1) Bengtsson, J., Ahnström, J. & Weibull, A. (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology* 42, 261-269.

2) EPOK (2013) *Mer biologisk mångfald på ekologiska gårdar?(More biodiversity on organic farms? Swedish only)* Swedish University of Agricultural Sciences Centre for Organic Food and Farming Uppsala, Sverige, 4 p. http://www.slu.se/Documents/externwebben/ centrumbildningar-projekt/epok/mngfaldsbroschyr_webb.pdf.

3) Heimer, A. (2009) *Ogräsbekämpning i ekologiskt lantbruk – möjligheter och begränsningar (Weed control on organic farms – Possibilities and Limits. Swedish only)* Swedish University of Agricultural Sciences Centre for Sustainable Farming (CUL), Uppsala, Sweden, 88 p.

4) KRAV (2013) Swedish Board of Agriculture webpage for organic seed. http://www. krav.se/jordbruksverkets-sida-ekologiskt-utsade

5) KSLA (2013) Odlingssystem och biologisk mångfald Exemplet Logården (Farming systems and biodiversity, The Logård example, Swedish only). *Kungliga Skogs- och Lantbruksakademiens Tidskrift* 152, 1-38.

6) LBU (2009) *Slututvärdering av miljö- och landsbygdsprogrammet 2000–2006 – vad fick vi för pengarna? (Final evaluation of the Environmental and Rural Development Programme 2006-2006 - what did we get for our money? Swedish only)* Swedish University of Agricultural Sciences, Uppsala, Sweden, 470 p.

7) Lindström, S. (2010) *Fröblandningar för den biologiska mångfalden i slättlandskapet (Seed mixes for biodiversity in lowlands, Swedish only)*. Hushållningssällskapet Kristianstad, Sweden, 43p. http://www.jordbruksverket.se/download/18.4b2051c513030542a9280004684/1307702683546/Fr %C3%B6blandningar+som+gynnar+f% C3%A5glar+och+insekter.pdf

8) Nilsson, U. (2007) *Ekologisk odling av grönsaker, frukt och bär – hinder och möjligheter för framtida utveckling (Organic farming of vegetables, fruit and berries – Obstacles and Possibilities for future development, Swedish only)* . Swedish University of Agricultural Sciences Centre for Sustainable Farming (CUL), No. 49 Uppsala, Sweden, 49 p.

9) Swedish Board of Agriculture statistics (2013) *Antal ekologiska husdjur år 2012 (Total number of organic animals in 2012, Swedish only)*. Statistikrapport 2013:06 (Statistics report). 16 p.

10) Swedish Board of Agriculture statistics (2012) *Nötkreaturssektorns uppbyggnad (The composition of the cattle sector, Swedish only)*. Statistikrapport 2012:03 (Statistics report). 43 p.

11) Official statistics of Sweden (2014) *Ekologisk odling 2013 (Organic farming in 2013, Swedish only)*. Statistics notification JO 10 SM 1403. 10 p.

12) Official statistics of Sweden (2013) *Jordbruksstatistisk årsbok 2012 (Statistical Journal of Agriculture 2013, Swedish only)*. Statistics Sweden, Örebro, Sweden, 398 p.

13) Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L.A. & Bengtsson, J. (2014) Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. *Journal of Applied Ecology* 51, 746-755.

14) Ögren, E. & Rölin, Å. (2009) Ökad odlingssäkerhet i ekologisk grönsaksodling med fokus på växtnäringsutnyttjande Länsstyrelsens rapportserie (Increasing farming insecurity with organic vegetable farming, focusing on utilization of plant nutrients, County council report series, Swedish only) 2009:8. Västmanlands län, Sweden, 120 p. http://www.lansstyrelsen.se/ vastmanland/SiteCollectionDocuments/Sv/publikationer/rapportserie/2009/Rapport2009-08-Okadodlingssakerhet_webb.pdf

9

The road to a secure and environmentally friendly food production

Agriculture must be developed to enable production of adequate high quality food supplies while farming is made as environmentally friendly as possible, which includes preserving soil fertility and natural resources. Agriculture based on new understanding of more environmentally friendly production methods that are applied successively over time is known as *integrated production* or *integrated farming*. The quality certification system Svenskt Sigill is currently working for such a knowledge-based environmentally friendly production of food, without forbidding the use of synthetically produced mineral fertilizers or pesticides. Farmers working under the Svenskt Sigill system follow a regulatory framework for long-term soil conservation, that includes needs-based fertilization and use of pesticides for weeds and pests. This includes rules for animal production that provide for assuring animals' needs and good health.

Future sustainability in agriculture will involve continuing development of principles for the smarter, more efficient use of production aids in farming with greater precision. Full utilization of energy, water, and plant nutrients, and appropriate conservation of the soil and environment will be the hallmark of this future agriculture.

Quality objectives for agriculture

The primary task for agriculture is to ensure adequate future supply of high quality food,[9,17] and that the production similar to the

Swedish national environmental objectives,[15] the following quality objectives should be promoted as the basis for developing future agriculture. These should cover production, quality, and the prerequisites for farmers.

- Emphasize the needs of crops in order to produce adequate amounts of good quality food.

- Production should be environmentally friendly – to the extent possible.

- Conserve farmed lands for future generations.

- Maintain high soil fertility and protect soils from pollution.

- Minimize the use of pesticides (natural and synthetic), and when used, it should be in a way that minimizes side-effects.

- Recirculate plant nutrients back to farm fields.

- Economize the use of finite raw materials.

- Conserve the diversity of the gene pool as a resource for breeding farm animals and new seed varieties.

- Treat farm animals well and ensure their needs are met.

- Attain and maintain satisfactory biodiversity and other biological values.

These objectives are the same for all types of agriculture – to achieve a secure and environmentally friendly food supply. Organic farming believes the method to achieve these objectives is by excluding mineral fertilizer and synthetic pesticides. But high quality agriculture should be based on science for new methods, improvements, and innovations.

Sustainable intensification of crop production

Since farmland is a limited resource and the demand for food will continue to grow, there is only one realistic path forward to meet future global food production needs. This involves more intensive production on existing farmland in combination with effective environmental protection and additional improvement to food quality.[18]

What does sustainable intensification mean? Would more intensive farming systems be the wrong approach for a long-term sustainable quality agriculture? And wouldn't it raise barriers to improving the environment and food quality? Wouldn't agriculture based on fewer inputs also have the least negative effects on the environment? Doesn't intensive farming exhaust soils, consuming finite natural resources, and increase leaching and environmental load? The answer to this is no – in most cases.

Sustainable intensification involves producing more food without increasing the amount of land necessary. Inputs must be used efficiently, and negative environmental impact minimized along with promoting other ecosystem services. Intensive agricultural systems emphasize the needs of the crop. Looking to the needs of the crop has been shown a successful approach for high yield and efficient and environmentally friendly production.

Prioritizing crops' needs, demands actively conserving and improving soil fertility. Extensive organic systems look only to improving the soil's fertility in the belief that good soil conditions are sufficient to achieve high productivity.

Many misunderstandings related to intensive farming systems must be corrected. Highly productive farming systems must always be combined with targeted environmental protection. And in fact, over the last twenty years, Swedish agriculture has been able to increase production while becoming much more environmentally friendly. This includes examples like reducing eutrophication through targeted environmental protection (with catch crops, riparian buffer zones and similar) which have been integrated into production.[6]

We have shown examples where leaching of plant nutrients to our waters is lower from highly productive systems than from organic (Chapter 6). Farming an extra crop in the fall to capture nitrogen that otherwise would leach out (catch crops) has been shown an effective mitigation measure, as have riparian buffer zones of planted vegetation to protect against erosion. We have identified how humus content increases with higher yields since this produces more material for humus formation in the form of crop residues (leaves, straw, stubble, and roots). Humus content increases with this type of production, along with the use of nitrogen, but only when nitrogen is utilized well by the crop.[13] Recent findings have shown that formation of humus from roots is equal to or greater than that from manure.[14] This raises the humus content in the soil, bringing better soil structure and greater water retention capabilities, all contributing to better use of the soil. This also means lower fuel consumption in tilling and soil management.

Intensive farming systems emphasize the crop, and high soil fertility. By focusing on the crop's needs, a stronger plant stand is created with less weeds, more effective utilization of nutrients, higher quality products, all with less environmental impact. There is, indeed, no conflict between high production, and high quality food with environmental protection.

New farming practices and improved crop production

We have also discussed the importance that controlled application of trace elements has in relation to food quality. In particular, the example from Finland regarding the application of selenium (Chapter 4). Using mineral fertilizer adds necessary nutrients to crops, and conserves soil fertility for future generations to use. Careful dosing of nitrogen fertilizer to meet the needs of the crops as they grow using sensor measurements has enabled controlling crop yields and protein levels.

We have shown that intensive (productive) farming systems are more energy efficient than extensive (low yield) ones (Chapter 5). The yield increase simply contains so much more energy than the energy consumed to produce the fertilizer, and transports, etc. Therefore, the energy requirements for manufacturing mineral fertilizer can be compensated many times over by the significantly larger energy harvested.[1] If production of nitrogen fertilizer where converted to utilize the yield increase of straw (renewable bioenergy instead of fossil), one hectare would suffice for the production of nitrogen fertilizer for approximately 20 hectares of crops.

Therefore, highly productive farming systems do not need to rely on fossil fuels, but rather the nitrogen fertilizer can be produced with renewable energy while providing a positive energy balance. Studies of highly productive farming systems indicate that less greenhouse gases are emitted than in low yield farming systems per kilo of product.

Developing sustainable and intensive farming systems to obtain greater yields on the same acreage, without adding more fertilizer and causing less environmental load is one of the important future challenges for agriculture. This requires new understanding and methods, and innovation. We will now discuss several possibilities for this.

TABELL 12. Effects of a conversion from annual to perennial cereal crops.[5]

Environmental variables	Amount per hectare and year	Total amount in Sweden per year
Nitrogen leaching	-12 kg nitrogen	- 12 000 tonnes nitrogen
Fixation of carbon dioxide	+ 1 ton carbon dioxide	+ 1 million tonnes carbon dioxide
Emissions of carbon dioxide	- 0.05 tonnes carbon dioxide	- 0.05 million tonnes carbon dioxide
Acreage taken opened to other production		100 000 hectares

New perennial crops instead of annuals

Many ideas to improve farming systems have been tested since the 1950s. These include intercropping with more than one crop in a single plant stand, growing two or more crops after each other every season, and bi-cropping cereals in short white clover as understorey vegetation. The basic idea with these is to cover fields with crops as long as possible to prevent having bare soil, which may cause nutrient loss, surface run-off, and erosion. One such strategy advocated by many plant breeders is to replace annual crops with perennials. Today, cereals are annual plants that must be sown every year, but they are derived from wild perennial variates. Breeding could develop perennial plants to replace some of today's annual crops.[20] Current efforts in the USA involve so-called wheat grass, but this could also involve improving on wild field pepperweed (Lepidium campestre) – as a replacement for oilseed – currently under way in Sweden.

Perennial crops would enable harvesting several years in a row without resowing. This would bring energy and work time savings (fall ploughing is one of the most energy demanding activities in farming), and this would have substantial environmental benefits. Nitrate leaching from farmland is largely the result of fall ploughed soils lying bare through the winter. Nutrients can be taken up more efficiently since a living root system is in place throughout the year, and weeds would have difficulty spreading when the ground is covered in vegetation. This would reduce leaching of nitrogen and phosphorus to nearby watercourses.

We still have no experience of conversion from annual to perennial cereals, but there is good reason to believe that perennial leys in most regards can be used as a model for perennial cereal crops. These both involve grass varieties which are harvested before the fall to remain over winter as stubble. Data from perennial leys has been used to estimate the environmental effect of such a conversion for cereal crops (Table 12).[5] The idea of maintaining yields, reducing energy use, and improving the environment by farming new perennial varieties is an ambition that would likely take 50 years to realise.

Greater focus on the nutrient quality of crops

When yields increase, and food has maximum nutrient quality, the supply of micronutrients and trace elements to the crop is an important aspect in crop production. While today's agriculture relies on the soil to deliver sufficient amounts of micronutrients, future agriculture needs to control and manage these flows as well. This application will not only include trace elements necessary for plants, but also those that humans and animals need for their requirements. The objective would be meeting our entire daily requirements of essential trace elements in the food we eat. Until now, only Finland has taken definite steps in this direction by fertilizing crops with selenium, which is not essential to the crop, but is for humans and animals. Sweden also has selenium poor soils, and such fertilization should therefore also be done. Copper, cobalt and nickel levels can also be very low in Swedish crops. Therefore, providing the trace and micronutrient requirements of plants, humans, and to a certain extent, animals should be possible through controlled application of these substances to farmed fields.

Creating key habitats for biodiversity

Species richness within agricultural landscapes is significant for many functions in the ecosystem, and these must be actively promoted. Farmed fields are not, in themselves, the most valuable habitats for biodiversity. Rather, this involves the many elements within the agricultural landscape, including non-arable outcrops, wetlands, hedges, ditches, and stone walls – all of which can be created to preserve specific habitats and biotopes to increase biodiversity.

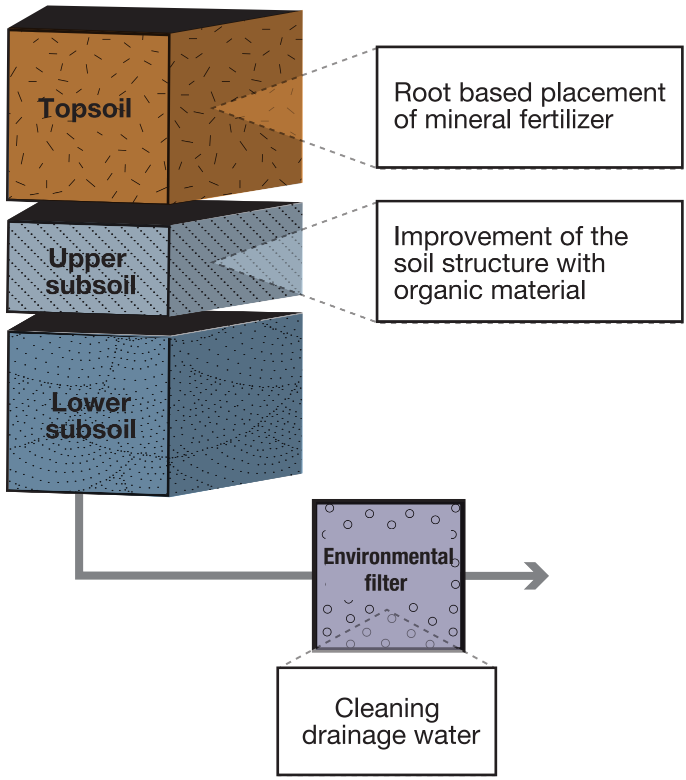
Farmers could receive targeted agri-environmental payments to create these biotopes. Targeted biodiversity measures will become the recipe for achieving the environmental objective of having a diversity of animals and plants. Special plants can be grown on suitable areas in farms to promote butterflies and threatened insects.

Overgrown fields, pasture land, and hayfields can be restored. Hedges, tree rows, and smaller tree plantations could be planted to promote bird life. Small areas in fields could be left unplanted for certain species of birds to use as protected nesting and feeding habitats. Border zones could be left next to fields by giving up a portion of yields, forage, or chemical pesticides in order to promote grass foraging wild animals such as deer and hares which then create the prerequisites for more species of plants, insects, birds, and predatory animals.

Modern agriculture, therefore, need not deplete nature in any way. Possibilities exist to improve the structure of landscape and to adapt farm practices to ensure that insects and birds, which are intimately tied to agriculture, can find their food, nesting sites, and cover.

Technology development to change land use

Greater efficiency in utilising energy and raw materials means that inputs have greater effect, costs per unit produced are lower, and environmental impact is less. For this reason, sensors are used to



FIGUR 23. New farming and environmental protection practices in farmed fields to increase production and minimize losses.

measure soil and crop conditions, enabling significantly greater precision in farming practice. Simple sensors are currently used to measure soil moisture to manage crop irrigation (as with potatoes), or variations in soil acidity to determine dosage for application of lime. Advanced sensor systems on farm equipment is used to measure the biomass and chlorophyll content of the crops to determine nitrogen fertilizer dosing to meet the crop's requirements exactly, and to equalize variations in the fields.

In another example, sensors can be developed to measure gases emitted by fungi to determine the extent of any fungal infection of crops in a field. Sensors are also being developed to provide advanced image and biomass analyses of plant stands to identify which weeds are present, as an aid in selecting the most appropriate weed control measure. Another possibility is linking information from several sensors to simulation models, enabling forecasting. Weather data can be combined with the scope of fungal infection for models to calculate whether to treat specific areas or the entire field. A successful concept could mean that information from several sensors is used for dynamic modelling and actions based on measurements and forecasts.

Fields are often compacted by heavy farm machinery, which damages soil structure, restricting crop root growth. Here, even limited damage to the structure can cause significant yield loss. Caring for the soil structure by minimizing ground pressure will become more important in the future fields whereby good soil structure will have the potential to produce very high yields. To limit soil compaction, current trials are attempting to control traffic on fields using GPS to follow specific driving tracks. These are then used in running all machines, from tillage, to sowing, fertilization, weed control, and harvesting. Tracked machines with lower ground pressure are also now being used. Development will eventually include trailers, manure spreaders, and combines so these cause less ground pressure than today.

Improving structure on fields under the topsoil (subsoils)

In many places in Sweden, crop root growth in the soil is impaired by compact subsoil structures.[10] This compaction is actually related to the last ice age when soils were deposited or impacted, which is most often the natural state. A compact structure in deeper soil layers has been shown to have permanent negative effects on yields. The crops' root growth is restricted so it cannot take up water and plant nutrients from deeper layers in the soil profile.

Studies show that better, deeper root growth, to layers 40 to 50 cm in the soil profile, can more than double yields.[7]

The basic idea is to offer the crops a larger pantry in the form of what can be described as a deeper topsoil. Roots primarily take up nutrients and water from the humus rich topsoil, while lower subsoils may be a compact and unutilized resource. In order to create a soil structure more receptive to roots under the topsoil, the ground should be tilled deeper and a large amount of organic material worked down into the subsoils once to create a long-term improvement to the structure. Improving soil in this way would be beneficial in many farming locations. Creating an aggregate formation and thereby, a long-term structure stabilization in deeper layers would also provide a fundamental improvement to fertility of farmland (Figure 23). Methods for such deep improvement in soils are currently being developed and yields could be increased significantly by increasing the volume of soil that plants can use. We believe this future Swedish farmland can be among the most productive in the world.

Fertilization and a closed plant nutrient cycle in society

The self-evident purpose of agriculture is to enable crops to fully utilize plant nutrients. Currently, mineral fertilizer is spread on the soil surface or is tilled down during sowing. By fertilizing with new methods, yields can potentially be increased, and plant nutrient uptake from mineral fertilizer can be improved. The fertilizer should be placed where the strongest root growth will be, and where uptake cannot be inhibited by dryness as is the case today.

Access to water is central to crops' capability to take up nutrients. Since the soil usually contains more moisture farther down than at the surface, and root systems grow larger where there is water, a deeper placement of mineral fertilizer may be required for greater crop uptake. Varying the fertilization depth, with a generally deeper placement is also less favourable for herbaceous weeds. This may also help reduce the formation of nitrous oxide. And generally, better uptake of nutrients would mean less leaching of both phosphorus and nitrogen.

Another significant step forward would be the availability of 'green' fertilizers. This would involve mineral fertilizer produced from renewable raw materials[3] (as from the ash of sewage sludge) and bioenergy (see Chapter 5 Figure 14).[1] A plant nutrient ecocycle between urban areas and countryside – recycling plant nutrients from sewage, sludge, and organic household waste to the fields – has so far not been able to be closed, despite recent improvement. It is especially important that phosphorus[4] is recycled since it is a finite resource. Sweden, among other countries, has instituted source separation of household waste, legislated for comprehensive efforts to prevent undesired environmental pollutants from entering wastewater, and banned landfilling of organic urban waste. But despite comprehensive treatment of urban waste, through composting or digestion, recycling the organic faction of this waste to farm fields is still difficult for various reasons.

These include high water content, low or no fertilization value, and the presence of undesired pollutants and pathogens. A possible way forward towards a functioning recirculation may be the recovery of plant nutrients from urban waste rather than returning the waste products themselves. Waste products can be incinerated or gasified and the mineral substances in the ashes produced become the product used in recirculation. After dissolving the ash, the minerals can be recovered through the separation of metals, phosphorus, and other plant nutrients.

Undesired metals can be recycled separately or landfilled. Phosphorous and other nutrients would then be used to manufacture mineral fertilizer, which would be free of cadmium. Concentrated and water soluble mineral fertilizer manufactured from this ash rather than virgin raw materials would be 'green' products that can be distributed the same way as with, and partly replace, today's mineral fertilizer.

Establishing a functioning plant nutrient ecocycle would be an important step towards more intensive production with less use of virgin raw materials.[12] However, forbidding mineral fertilizer, as we see in organic farming, would exclude this concept, inhibiting the creation of such a recycling circuit between city and countryside.

Environmental filter for farmland

Future agriculture will still cause leaching of plant nutrients and pesticides. Leaching of plant nutrients is, for example, greater from farmland than from natural lands, and more undesired nitrogen gases are released from farm fields than from other types of land. Therefore, new methods must be implemented to reduce the environmental load from farming. In areas with especially polluted waters, filter material is now being tested in drainage ditches in an effort to purify farm drainage water. Leached phosphorus and pesticide residues can be absorbed by this material which has a large specific surface similar to carbon filters. To improve rivers and lakes, environmental filters for farmland can be an important component in future cultivation systems.

Literature Chapter 9

1) Ahlgren, S., Bernesson, S., Nordberg, Å. & Hansson, P-A. (2009) Ammonium nitrate fertilizer production based on biomass – environmental effects from a life cycle perspective. *Bioresource Technology* 99, 8034-8041.

2) Burney, J.A., Davis, S.J. &. Lobell, D.B (2010) Greenhouse gas mitigation by agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America* 107, 12052–12057.

3) Cohen, Y., Kirchmann, H. & Enfält, P. (2011) Management of phosphorus resources – historical, perspective, principal problems and sustainable solutions. I Kumar, S. (red.) *Integrated Waste Management Volume II*, Open Access, s.. 247–268. www.intechweb.org.

4) Cordell, D., Rosemarin, A., Schröder, J.J. & Smit, A.L. (2011) Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. *Chemosphere* 84, 747–758.

5) Fagerström, T. & Wibe, S. (2011) *Genvägar eller senvägar – vad kostar det oss att avstå ifrån gentekniskt förädlade grödor i jordbruket? (Shortcuts or detours – what does it actually cost to refrain from genetically improved crops in agriculture, Swedish only)* Report to the group of experts for environmental studies 2011:3. Government offices, Department of Finance, Stockholm, Sweden, 98 s. http://www.ems.expertgrupp.se/uploads/documents /ems2011_3tillwebben.pdf

6) Fölster, J., Kyllmar, K., Wallin, M. & Hellgren, S. (2012) *Kväve- och fosfortrender i jordbruksvattendrag. Har åtgärderna gett effekt? (Nitrogen and phosphorous compounds in farm watercourses. Have these measures had an effect? Swedish only)* Swedish University of Agricultural Sciences, i Department Aquatic Sciences and Assessment, report 2012:1. Uppsala, Sweden, 66 s. http://www.slu.se/PageFiles/43668/F%C3%B6lster%20 2012%201%20ver2%20N%C3%A4rtrend.pdf.

7) Gill, J.S., Sale, P.W.G. & Tang, C. (2008) Amelioration of dense sodic subsoil using organic amendments increases wheat yield more than using gypsum in a high rainfall zone of southern Australia. *Field Crops Research* 107, 265-275.

8) IAASTD (2009) *Agriculture at a Crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development*. Synthesis report. McIntyre, B.D. et al. (Ed.) Island Press, Washington, USA, 95 s.

9) Isaksson, C. (2012) *Maten och makten. Hur ska den nya världen mättas? ((Food and Power how will the new world be measured? Swedish only)* Ekerlids Förlag, Stockholm, Sweden, 223 s.

10) Kirchmann, H. (1994) Comparison of six subsoils of the Swedish long-term fertility sites with respect to the utilization of N, P, and K. *Kungliga Skogs- och Lantbruksakademiens Tidskrift* 133, 65-69.

11) Kirchmann, H. & Thorvaldson, G. (2000) Challenging targets for future agriculture. *European Journal of Agronomy* 12, 145-161.

12) Kirchmann, H., Cohen, Y., Enfält, P. & Jakobsson, C. (2012) Nutrient supply in agriculture – abundance today and shortage tomorrow? I Jakobsson, C. (red.) *Sustainable Agriculture.* The Baltic University Programme, Uppsala University. Elanders Tryck, Sweden, s. 19-29.

13) Kätterer, T., Bolinder, M. A., Berglund, K. & Kirchmann, H. (2012) Strategies for carbon sequestration in agricultural soils in northern Europe. *Acta Agriculturae Scandinavica, Animal Science Section A* 62, 181-198.

14) Kätterer, T., Bolinder, M.A., Andrén, O., Kirchmann, H. & Menichetti, L. (2011) Roots contribute more to refractory soil organic matter per unit carbon than above-ground crop residues as revealed by a long-term field experiment. *Agriculture, Ecosystems and Environment* 141, 184-192.

15) Swedish EPA (2012) *De svenska miljömålen. En introduktion (The Swedish Environmental Objectives, and Introduction)*. Swedish EPA publications, Stockholm, Sweden, 26 s.

16) Olofsson, M. & Öhman, D. (2011) *Matens pris: boken som matindustrin inte vill att du ska läsa (The price of food: a book about the food industry you don't want to read, Swedish only)* Reporto Förlag AB, Stockholm, Sweden. 274 s.

17) Randers, J. (2012) *A Global Forecast for the Next Forty Years. 2052.* A report to the Club of Rome. Commemorating the 40th Anniversary of 'The Limits to Growth'. Chelsea Green Publishing, England, 416 s.

18) Royal Society (2009) *Reaping the benefits: science and the sustainable intensification of global agriculture.* Policy document. http://royalsociety.org/uploadedFiles/ Royal_Society_Content/policy/publications/2009/4294967719.pdf.

19) SCB (2012) *Hållbarhet i svenskt jordbruk(Sustainability in Swedeish Agriculture, Swedish only)*. Statistics Sweden, Swedish Board of Agriculture, Swedish EPA, Federation of Swedish Farmers. SCB Tryck Örebro, Sweden.

20) Sylwan, P. (2011) Perennerna ska revolutionera jordbruket (Perennials will revolutionize agriculture, Swedish only). *Forskning och Framsteg (Research and Progress)* no 2.

10

Summary questions and answers

The pros and cons of organic farming have raised many questions in recent years. Answers often appear to be contradictory – depending on whether the person answering is for, or against, organic farming generally. Too often answers are based on hope, rather than relying on scientific fact. We have compiled a few common questions we have been asked over the years in various contexts. Our responses are based on current scientific understanding in these fields. We feel this is an appropriate way to summarize the issues addressed in this book, and hope the reader can thereby obtain a clear, straightforward description of conditions within organic farming.

Farming philosophy and sustainability

Organic farming is considered to be best adapted to nature, and therefore better for the environment than 'chemical agriculture'. In that case, isn't it better for the government to support organic farming to achieve a more environmentally friendly agriculture?

Organic farming involves less efficient utilization of farmland, producing lower yields without reducing greenhouse gas emissions and nitrate leaching. Therefore, 'environmental subsidies' for organic farming cannot resolve the environmental issues caused by agriculture. Providing financial aid through targeted, effective environmental measures in all types of agriculture may, however, be justified.

In organic farming, food production is based on natural principles and is therefore based on harmony with nature. It is therefore, self-evident that only natural agents and methods should be permitted. Shouldn't this be the guiding principle for all agriculture?

This view is not supported by scientific understanding of how nature functions. Basing agricultural production on principles of nature, attempting to emulate natural processes actually contradicts the purpose of agriculture. Agriculture presumes the transformation of natural ecosystems to man-made agroecosystems. Agriculture, by nature, involves growing improved crops, fertilization, weed control, and, in the end, removal of the farmed crop from the land. These interventions into nature – which are indeed what 'cultivation' is – cannot and perhaps should not emulate natural ecosystems or natural processes.

All agriculture involves managing and controlling nature. Natural systems never involved applying any pest control substances, nor the application of large amounts of manure. In regard to accepted 'natural' means, only thorough study and testing can determine whether these are suitable or not. These so-called natural substances can have their own negative impact on natural systems and on humans. Here again, comparing 'natural' to 'synthetic' medicine can illustrate. There are natural medicines that are effective in treating certain diseases, but the vast majority of useful medicines are synthetic. In short, natural farming substances and methods are most often insufficient, and are not necessarily better.

Humans must cultivate and manage nature in the best possible way to protect arable land from erosion and contamination, and to maintain soil fertility while minimizing losses from these systems. And not least, this should produce sufficient amounts of nutritious foodstuffs.

Organic farming is certainly based on natural philosophies, and not science, but does that matter? Current research uses scientific methods for both organic and conventional farming. Doesn't the basic idea mean anything?

The central ideas of the founders of organic farming (Steiner, Balfour and Rusch) regarding how agriculture functions and how our foodstuffs should be produced still permeate organic production as a foundation, basic idea, and its trademark. The most tangible example of this is the ban on using soluble mineral fertilizer, which is considered to have a negative impact on both food quality and the environment. All research projects looking into organic farming are designed around this precondition of excluding soluble mineral fertilizers. There is no scientific basis for doing so, but this is still the controlling basis for research into organic farming to this day. In this, natural philosophy overrides science. Our view is that developing sustainable agriculture would move forward more quickly without such ungrounded limitations. The environmental impact of modern agriculture has been known for some time. Research into organic farming provides no benefit for conventional farming to help address environmental issues. This failure is then used to justify organic farming. Research into organic farming and practice likely obstructs, rather than promotes, development toward sustainable agriculture.

Aren't locally grown products always organic?

A common perception is that locally grown products are always organic, but this is not the case. Locally grown products are simply those products produced locally, meaning they are transported shorter distances, and often have been stored for shorter periods. But there is no definition of what can be considered 'local' in this context. Most often, locally grown does involve fresher, and more flavourful foodstuffs – positive quality properties gained regardless of the type of farming system.

Can conventional farming really be sustainable when mineral fertilizer must be applied every year? For example, won't a shortage of phosphorus fertilizer become a significant problem within 30 years, since it is a finite resource?

The extent of existing phosphorus supply – whether it will last 30 years or longer – is currently under debate. In recent studies, the US Geological Survey has suggested a greater supply remains, especially in Morocco, West Sahara and China.

The most recent forecast is that reserves should last over 300 years. Regardless of the actual situation, humans will eventually need to develop an effective ecocycle. And the sooner, the better. For phosphorus, the most important consideration is that it will not run out – as with oil and gas – but rather that can be recycled from our waste.

Conventional agriculture is dependent on fossil fuels for the energy intensive production of nitrogen fertilizer. How could organic farming, which uses legumes to biologically fix nitrogen, not be more sustainable? Isn't it necessary for agriculture to become less dependent on fossil fuels in order to be more sustainable?

The application of nitrogen fertilizer to crops in conventional farming brings significantly higher yields – of both foodstuffs and straw – as compared to organic farming. Yields in cereal production are higher on the order of 2-3 tonnes per hectare which is also the case for straw. Nitrogen fertilizer can be produced using energy from renewable organic material, such as straw or wood. Therefore, the straw from a single hectare of conventionally fertilized farmland provides enough energy to produce nitrogen fertilizer for 20 hectares. Using nitrogen fertilizer, therefore, provides an extremely positive energy balance, showing it can be produced sustainably without fossil fuels. Using legumes as a source of nitrogen presents its own problems, since these do not produce equal gains in yields as mineral fertilizer, and they cannot be grown every year. Moreover, growing legume crops also often leads to significant leaching of nitrogen.

Is organic food really such a 'bluff', where consumers are actually fooled?

As we have discussed at several points in this book, organically produced foodstuffs provide no clear advantages in terms of quality, health, or the environment. Where any such advantage can be found, this can be created more efficiently by changing conventional farming practice. Despite this fact, society is investing significant resources into organic production, while consumers also pay higher prices for organic products without getting more for their money. Consumers are thereby misled, and so pay for good intentions.

Organic farming is rarely criticized in public. Why?

Many feel self-censored to be positive to organic farming. Many people are deeply convinced of the superiority of having food produced 'according to nature's way' and that organic farming is therefore better than conventional. Still, there are no scientifically based studies that demonstrate this.

Sound development in democratic society must be built on policies that are based on available, factually derived knowledge, which also naturally applies to agriculture. We therefore feel it important that any critical views contradicting the tenets of organic farming should be presented and discussed factually.

Doesn't organic farming drive development forward – especially towards more environmentally friendly conventional farming.

Organic farming systems are subsidised by public funding. In Sweden, nearly SEK 500 million (€ 50 million) is paid annually in direct subsidies to producers, and additional tax funding is earmarked for research. Moreover, there is the national objective for 25 per cent of all public food procurement through county councils and municipalities to be organically produced. We consider that this funding would have greater positive impact through investment in developing modern agriculture free from ideological overtones. It would have greater impact if directed towards promoting measures for greater resource efficiency, biodiversity, and reducing environmental impact. Subsidizing organic farming systems, then, impedes development of a more environmentally friendly agriculture.

Impact on food

Can organic farming supply the world population with food? Isn't organic farming preferable in a global perspective for feeding our growing population?

The food supply cannot be secured through organic farming in developed countries since yields are 50 per cent of those from conventional farming. Relying solely on organic farming would lead to serious food shortages, and even famine. The greatest problem with organic farming is, indeed, its inability to produce sufficient amounts of foodstuffs. This applies even if such production could be made sustainable. Yield levels in developing countries can be raised by applying current, and improved understanding of how to best utilize local prerequisites. This could be called organic, but application of mineral fertilizer to the often nutrient depleted soils would multiply yields.

Why are yields only 50 percent in organic farming? Can't organic production also be raised over time through more intensive research to provide sufficiently high yields to thereby provide organically produced food for the world's population in future?

This ignores several fundamental factors in agriculture. To maintain and increase production, crops must be provided sufficient amounts of plant nutrients. Organic systems today lack sufficient plant nutrients and permitted fertilizers that are applied can become only partially plant available. This fact cannot be changed as long as organic farming systems forbid using mineral fertilizer that is immediately available to growing crops.

Protecting crops from plant diseases and competition from weeds is another problem. There are currently no practical, applicable measures available in organic farming that can address this problem sufficiently well. Resolving these issues in future is not likely, but some improvements are possible.

Can't organic food production be doubled by farming twice as much land?

The world's land with sufficient value for growing agricultural crops is already being cultivated. There are only a few regions where smaller areas of forest or natural lands can be converted to food production. Land can also be lost to agriculture due to urbanisation and climate change. Doubling the acreage of farmed land is therefore not possible in a global perspective.

A reduction of yields in organic farming is actually not a real problem if we change are food habits, as with eating less meat or becoming vegetarian. Wouldn't organic production be enough then?

It is certainly possible that if the entire world population turned to vegetarianism, organic food supply would be sufficient. Some medical research also finds that a more vegetable rich diet has positive health effects. Even so, such a change could also be made based on conventional farm production, which would free a large portion of today's farmlands for use in production of renewable energy or other raw materials. In short, the world's dietary composition should be based on science, not avoidable food shortages.

Is organic food more nutritious, and are there any health benefits derived from eating organic food?

Many comparative studies over the last 30 years have shown that few quality differences exist between organic and conventionally produced food. When significant differences have been shown, they show mixed benefits. At times conventional is found to be better, at times organic. In other words, buying organic products is no guarantee for more wholesome food. In the end, dietary composition is important for human health – but this involves the mix of foods on your plate.

Generally, conventionally grown wheat has higher protein content. Is it possible that this promotes the formation of acrylamide in bread production? Would nitrogen fertilization thereby be a cause of cancer?

Acrylamide is known to induce cancer, as well as causing nerve system damage. In 2002, it was found that acrylamide is formed naturally when cooking food (when heated above 120 degrees) through a reaction between sugars (glucose and fructose) and the amino acid asparagine.

The levels of free asparagine in cereals may have an effect on how much acrylamide is formed during baking. Since there is a relationship between nitrogen fertilization and higher protein levels in cereals, and between levels of free asparagine and nitrogen fertilization, the question is relevant. The European Food Security Authority, as regulatory body for food production, has issued indicative values for various types of foods as guidance for related risks. These are for soft bread, 150, and for whole-grain bread and hard bread, 500 micrograms acrylamide per kilogram. The average levels in soft bread and hard bread, respectively, vary between 100, and 300 micrograms acrylamide per kilogram. The extent to which conventionally grown cereals may lead to greater formation of acrylamide has not been determined yet. But as a comparison, we can note that 29 per cent of average intake of acrylamide through diet is from coffee and 27 per cent from bread.

Does high gluten content due to nitrogen fertilization contribute to gluten intolerance and cereal allergies?

Gluten is made up of proteins that are part of wheat, rye, and barley, but not oats. Protein levels in growing crop stands are measured on many farms, and through adaptive nitrogen fertilization, the levels of raw proteins (and thereby gluten) are raised to improve baking properties of the wheat. Nordic populations never consumed wheat to any significant degree prior to the 1800s when the proportion of wheat increased from approximately 5 per cent of cereal production to nearly 15 per cent by the 1920s. These populations are therefore not genetically adapted to today's gluten levels. Similar reasoning is used regarding lactose intolerance among Asiatic populations. Gluten intolerance is no longer considered entirely genetic, but is also seen to be linked to the age when wheat is first fed to infants and how much they then receive. Small amounts of gluten can cause symptomatic reactions in allergic or intolerant individuals. However, whether grown organically or conventionally wheat can have higher or lower levels of gluten. In this case, no clear difference can be seen between conventional and organic farming in relation to possible effect on gluten intolerance.

Are pesticides needed at all? When the crop becomes infested with pests, this shows that it is weak, and poor quality, and that there are more basic problems with the farm.

Disease is not necessarily a sign of weakness, but rather, plants become diseased or 'ill' much like humans and animals. Pesticides can be seen as medicine used in agriculture to cure disease in infested crops.

Do residues from chemical pesticides in foodstuffs present any risk?

Of course pesticide residues in our food must be restricted. Sweden and the EU have set strict limits on permitted residue levels of various pesticides. These limits are set with added safety margins to ensure food can be consumed without any known health risks.

For our most important foodstuff, drinking water, the limits for any single pesticide is 0.1 microgram per litre. This is a very small amount, and shows that society-at-large is seriously addressing these residues in our food. Also important to remember in this context, is that many of our foodstuffs contain substances that form naturally in much higher concentrations, and these may be much more toxic than synthetic pesticides. Many of these are permitted in our food at much higher limit levels. Examples of these include solanine in potatoes, and caffeine in coffee. Both of these are widely consumed daily. In other words, exposure to natural toxins is generally greater than to synthetic pesticides. The biblical reference to 'strain a gnat and swallow a camel' can easily apply to when we discuss toxins in our foods.

Environmental Impact

Isn't it self-evident that organic farming is environmentally friendly since everything that is used is natural?

Proponents of organic farming present it as a radical environmental alternative, but every type of agriculture has an environmental impact. All agriculture involves significant impact on the environment in every day practice, through ploughing, harrowing, weeding, fertilizing, and such. For example, there is no clear scientific reason that banning soluble mineral fertilizer is more or less environmentally friendly. Leaching of plant nutrients from organic farms, especially when comparing per kilogram of produced food, is often greater from organic than from conventional agriculture.

Doesn't organic farming increase soil fertility, so that we leave better soils to future generations?

Soil fertility does not improve with organic farming, rather this system slowly depletes soils of plant available nutrients due to the absence of soluble mineral fertilizer. Other factors also contribute to declining fertility, including ineffective weed control, leading to propagation of a variety of competing weeds, and that recirculating plant nutrients from town to country is not permitted. The humus content of soil is also an important factor in fertility, but organic farming does not lead to higher levels of humus when comparing equivalent crops and crop rotations.

Wouldn't the release of nitrogen and phosphorus to the ocean decline if more farmers converted to organic farming?

Nitrate leaching usually increases from organic farming, while phosphorus leaching is approximately the same when comparing conventional and organic farming. If you also consider the significantly reduced yields from organic farming, and look at leaching losses per produced amount of food, these become significantly higher for organic farming.

The reason for higher nitrate leaching from organic farms is that organic fertilizers release plant nutrients year round. With no growing crops to take these up in the off season, nitrogen that is released then leaches out. Soluble mineral fertilizer is applied to growing crops when and in the amounts needed, so only small amounts of nutrients remain after harvest.

Is organic farming best for the climate?

Large scale organic farming would lead to a significant increase in primarily carbon dioxide. The lower production from organic farming leads to lower carbon levels in the soil. Moreover, the lower production requires cultivation on more acreage to meet food requirements. If this acreage is taken from natural land, the carbon levels in these soils will decrease, causing greater emissions.

Large scale organic farming

Current public policy in Sweden is to have 20 per cent arable land to be organically farmed, which you are all critical to. Is such criticism justified?

Many policy makers believe this is a good decision that benefits the environment and human health, and that it contributes to a more sustainable agriculture. But this objective was set well before 2000, when more people were convinced organic farming had these claimed benefits. The scientific basis for this was, however, limited.

Criticism arose only after 2000 when results from long-term studies and official Swedish statistics on organic farming showed yields were 50% lower. Environmental load was also found to be significantly greater per unit of food produced than in conventional farming. Differences in food quality have not been found though many studies have been conducted over this period. In other words, now that understanding is becoming clearer, this target must be questioned and revised.

What would be the most tangible effects of converting all Swedish agriculture (100 per cent of the total arable acreage) to organic practice?

This would result in:

- Food supplies in Sweden would become a serious problem due to substantially reduced yields. The country would therefore become much more dependent on food imports for a secure supply of foods.

- To make up this loss in production in Sweden alone, a total of 1.7 million hectares of additional land (including forest and natural lands) would need to be converted to agriculture. This would nearly double the nutrient loss and climate impact of agriculture in the country.

- Long-term plant nutrient supplies in full-scale organic farming would be unsustainable and lead to soil depletion, as no external sources of plant nutrients from conventional agriculture would be available.

- Environmental problems related to synthetic pesticides would be eliminated.

- We would experience a substantial increase in weeds and plant diseases, which would further impair crops like potatoes, and oilseed rape.

- Sweden's environmental objective for reduced climate impact and nutrient loads to the Baltic would be very difficult to achieve.

Isn't producing less food with full-scale organic farming positive, since we would then be forced to change our diets to be mostly vegetarian?

Convinced ecologists try to think positively to also a see benefit in having less food produced. This involves reasoning around facts that are inconsistent with belief. But changing food habits is a radical reduction in the quality of life, if these changes are not voluntary. Trying view something as basic as insecure and insufficient food supply in a positive light is, in essence, unsound.

Misunderstandings regarding mineral fertilizer

Isn't it obvious that mineral fertilizer, which is unnatural and manufactured using industrial chemical processes, should not be applied to the soil? Mineral fertilizer is unnatural.

Mineral fertilizer contains exactly the same minerals that plant roots take up from the soil. Using mineral fertilizer provides the exact plant nutrients that crops need.

Mineral fertilizer poisons the soil and kills microbial life.

No, the minerals in mineral fertilizer are essential for both plants and microbes.

Biological fixation of nitrogen by legumes can replace mineral fertilizer.

In principle this may be so, however in practice the nitrogen that is fixated is never sufficient, resulting in lower yields. Moreover, bringing nitrogen fixated by legumes grown one season to crops grown in the next is difficult to manage, and this often leads to more leaching.

Use of nitrogen fertilizer is not sustainable since its manufacture is so energy intensive and based on fossil fuels.

This is incorrect, nitrogen fertilizer can be produced using renewable energy. But, even if produced from fossil energy, nitrogen fertilizer is more efficient since many times more energy is bound in the increased biomass produced due to fertilization.

Production and use of nitrogen fertilizer causes significant greenhouse gas emissions and is not climate smart.

There is no final answer to this. Findings seem to depend more on the systems studied and study methods. Removing nitrous oxide during production of nitrogen fertilizer is important, and catalytic converters for this purpose have been installed in recent years. Data on emissions from fertilizer in soils provides no clear indications.

Using mineral fertilizer leads to significant leaching of plant nutrients into watercourses.

This is only the case when the dosage of fertilizer exceeds the crop's needs, which is more common with application of manure. Understanding in regard to needs-based fertilization and sensor technology currently enables very effective use of nitrogen fertilizer. Nitrogen leaching from mineral fertilizer is in most cases always lower than from organic fertilizers when equal amounts of nitrogen are applied.

We can produce enough food without mineral fertilizer.

This is not correct, yields become much lower since manure and other organic fertilizers are insufficient. This makes food shortages inevitable.

Are there any risks related to using soluble mineral fertilizer?

Using mineral fertilizer carries two risks – incorrect use, and failure to implement necessary soil conservation measures. Mineral fertilizer is an effective means to apply nutrients to crops. This presumes the correct type and amount of fertilizer is applied at the right time. Doing so brings high, good quality yields.

The other risk is relying too heavily on mineral fertilizer to guarantee high yields, while ignoring other necessary soil conservation measures. For example, using only mineral fertilizer cannot replace a varied crop rotation system, which is necessary to reduce weed propagation and disease. Mineral fertilizer cannot directly improve the soil structure and will not overcome problems with soil structure requiring different crops, structural liming, application of organic material, or mechanical management practices. Wind and water erosion of farmlands can only be prevented using specific protective measures. Use of mineral fertilizers is often blamed when farm soil has deteriorated, while more often this is caused by poor soil conservation practice.

Final words

Organic production is seen as the route to a more sustainable agriculture, but research has shown this is not correct. Organic farming significantly reduces crop yields, and can therefore not feed a growing population. Organic food is not more wholesome, nor is this type of agriculture better for the environment.