Urban Areas - Rural Areas and Recycling - The organic way forward?

Proceedings from NJF-seminar No. 327
Copenhagen, Denmark 20-21 August 2001

Jakob Magid, Artur Granstedt,
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Danish Research Centre for Organic Farming

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Preface

With the NJF seminar "Urban areas – Rural areas and recycling – the organic way forward?" we wanted to set the scene for discussions on sustainable urban and rural co-development. The themes ranging from "local integration of food production, food processing, distribution and consumption" to "aspects of recycling in the whole food chain" attracted a diverse group of scientists and NGOs working with both technical, biological, financial and social aspects of rural and urban co-development.

Despite the diversity of the approaches and subjects it was clear that a substantial cross-fertilisation occurred among the participants. Hopefully, the coming years will see an increased effort on linking the urban and rural areas together in a more sustainable manner, both in terms of food systems and with regard to recycling.

In this report the various presentations are collected and presented with the aim of further stimulating the future networking and as well as research and development processes. This would not have been possible without the efforts of the individual authors, the editorial group, and the organisers of the workshop.

Last, but not least, we want to give credit to DARCOF, whose staff have been very helpful and diligent in the production of the final version of the proceedings. Our sincere thanks are therefore extended to all those involved in the workshop and the creation of this book.

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Contents

Introduction

In society as a whole there is a wish to support a sustainable development. In recent years the public has been concerned with agriculture, and the population has been particularly supportive of organic farming in their consumer behaviour. To this date there has been rather less concern with the sustainable functioning of the urban areas, and only a few persons have started to talk about "organic cities".

One of the more fundamental problems in present-day-society is the dissociation of urban areas from the rural surroundings. This has given rise to a cultural estrangement in view of the fact that many if not most, urbanites no longer have close ties to rural life. Another aspect of this dissociation is the lack of recycling of nutrients and organic matter from urban areas. For years agriculture has spent huge resources on energy-intensive synthetic fertilizers, while nutrients lost from the urban areas pollute the environment – nutrients that may have replaced some of the synthetic fertilizers used in agriculture. In one provocative chapter of these proceedings it is argued that the energy requirements of the currently dominant food production and distribution system by far exceeds that of both private housing and transportation systems, and that future limitations in fossil fuel use should lead to a ruralisation of urban settlements to allow a better integration of the various life support systems.

The sustainable functioning of urban areas has thus been of growing concern in the Nordic countries, and a number of researchers have set out to investigate possibilities for establishment of more sustainable food systems, with a focus on commercially viable strategies.

The aim of the seminar "Urban Areas - Rural Areas And Recycling. The Organic Way Forward?" held in August 2001 at KVL was to present and stimulate research in a number of different themes:

- Qualitative, ethical, environmental, and resource conservation consequences of local integration of food production, food processing, distribution, and consumption
- Documented sociological and financial experiences of local cooperation between consumers, processors, distributors, and farmers
- Aspects of recycling in the whole food chain (within farming systems and between town and countryside, including distribution and processes)
- Scientific and personal experiences of eco-villages, nutrient recycling, local self-sufficiency in food, and other resources
- Rural and urban co-development, now and in the future
- Methodological aspects of research in organic farming related to the themes

These themes are by and large covered by the 19 contributions to these proceedings. For the sake of clarity the volume has been structured into two parts, the first being concerned mainly with the food supply and distribution systems and the second with a focus on the recycling of nutrients and organic matter.

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Rural - urban co-development - challenges to post-industrial society

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The World Commission (1987) pointed out that sustainable development in general is a prerequisite to alleviate fatal threats to human future. In this note[1] it is stated that it is necessary to return to basic concepts and reflections to ensure that the aim, means, and context are remembered when radical changes to gain sustainability are designed. In particular this is the case when humanity's social interplay (i.e., technology) with natural life support systems is in focus. Thus, the note is founded on a restatement of basics linked to the essential challenge facing post-industrial societies. In that light it is revealed that the current reactions to the challenge are insufficient because sustainability implies radical rather than marginal changes and that the radical changes *inter alia* imply a new design of rural - urban co-development.

Basic statements as points of departure

The basic challenge facing post-industrial societies is not rural-urban co-development but sustainable development. In this perspective sustainability is the aim and rural-urban co-development one of the necessary ways. Thus, the point of departure for this note will be the connection between ecology and sustainability.

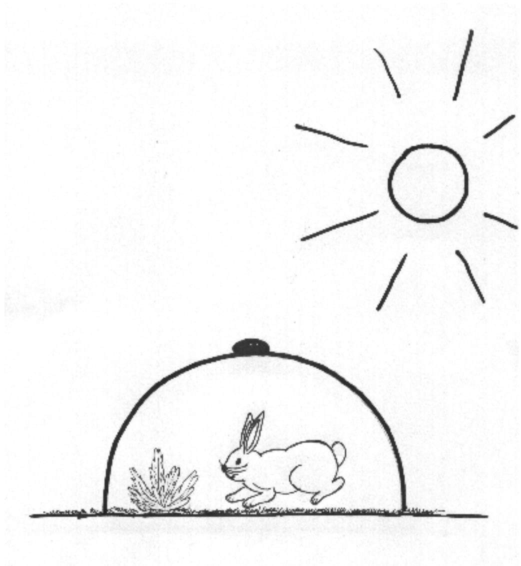
The World Commission emphasised the concept of sustainability in 1987. The term *sustainable development* was reshaped to describe a solution to current threats to the global society: unequal distribution of resources in time (inter-generational) and space (developing versus developed nations) implying overuse of non-renewable resources besides pollution that damage natural mechanisms. Both overuse and pollution represent a fatal threat upon the future prospects of the human species and imply the need of radical changes. Sustainable development was then introduced as the headline of the necessary radical changes. In the meantime, sustainability has been interpreted and used in a widespread range of contexts that infer the necessity to state the basics.

1 The present note only includes a limited number of references. However, the author owes a debt of gratitude to the colleagues in the transdisciplinary network concerning EEA (re Ingemann, 2001b) for shaping the transdisciplinary reflections.

Figure 1

Natural life support systems (NLSS)

- Natural capital
  - renewable
  - non-renewable
- Natural mechanisms
- Natural energy
  - sun



Sustainability is clearly related to the basic principles of ecology. Food and gas are the basic cyclical elements of ecology while energy provided by means of sunshine makes the system work, as illustrated in figure 1 with the rabbit and lettuce under an airtight dish cover; alone they would die, brought together they form a living system with two cycles. In the gas cycle, the plant and the rabbit are symmetric and equal; both are recipient technologies able to transform waste (oxygen and carbon dioxide) to resource (carbon dioxide and oxygen). In the nutrient cycle, however, the plant is autotroph and the animal heterotroph; thus, only the plant is able to reprocess nutrients from waste. The elements and relations in that system constitute the foundation of understanding and assessing sustainability. Resting for a moment by the simple picture of ecology, there are no problems of sustainability when the species are left alone in their ecological cycles and evolution. That is so, because the basic mechanisms of nature are then exclusively in power. In that case the ecosystems will ensure that basic mechanisms will function and that the totals of living organisms automatically are balanced out to ensure that no organism extends the limited capabilities of the system regardless whether the perspective is local or global. This system can be labelled as a natural life support system.

In relation to natural life support systems sustainability presumes two crucial points. One, actions that involve hazardous damage to the basic cyclical mechanisms must be avoided. Two, balance between the number of organisms - i.e., number of rabbits and amount of lettuce - must be ensured. So, we have to consider both function and capacity.

In nature, food is nothing but a biological input and the system is outbalanced by its own means. Problems do arise when one of the species (i.e., mankind) evolves and applicates skills (i.e., technology) to offset or modify the function, or to go beyond the bounds of the system's carrying capacity for instance due to overuse of resources. When so, mankind incurs responsibility in relation to *sine qua non* for fellow men in both time and space.

When human beings have entered the picture, it is also necessary to consider sustainability and natural life support systems from a social point of view and then ask: Does present social organisation support or counteract damage according to function and balance according to capacity?

Related to the latter questions complex difficulties emerge, as food in the modern world is not only a biological input but a commodity, too. Then supplementary food is a source of revenue to farmers, industries, distributors, scientists, bureaucrats, etc. Besides, these actors are gathered in social institutions and are parts of societal structures. These complex structures and institutions - producing and reproducing social experience and knowledge - can support or counteract sustainability. From a social scientific point of view structures and institutions in which technology is adapted and evolved are then important analytical concepts when sustainability is studied. Structures are the material and institutions the immaterial framings of society. (Ingemann, 2001a)

Technology

Now focus is turned to human production and a couple of statements about technology are needed.

It is a basic function of any society to provide and ensure means by which the members can comply their reproductive needs. These imply productive activities; technology then becomes a crucial affair from a social point of view and a sphere by which a society might be characterised.

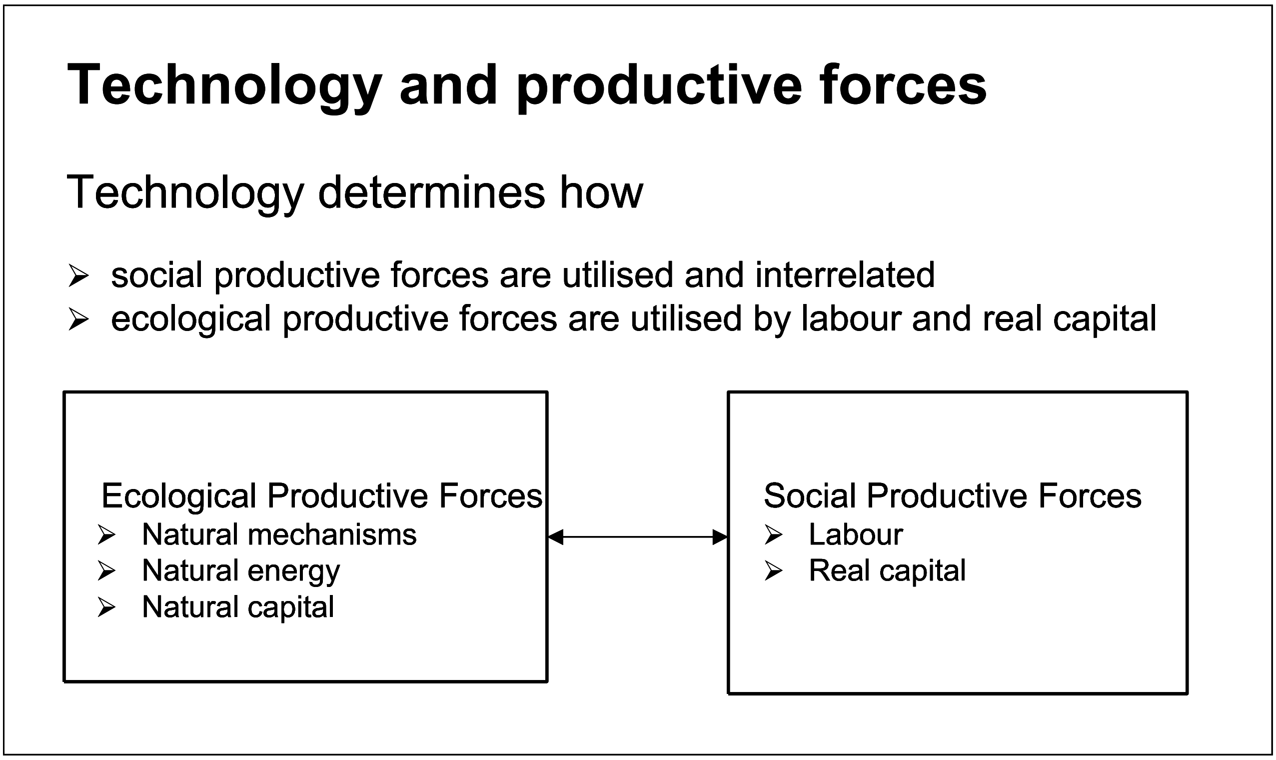
'Technology' in everyday comprehension is most often interpreted as similar to technical devices and matters. This implies an inadequate limitation of the conceptual meaning where crucial social dimensions are cut off. In the Greek origin the concept consist of two parts, *techne* and *logos*. *Techne* is art and craft while *logos* is knowledge.

Combining *techne* and *logos* we face productive and reproductive activities, the tools, the labour with certain skills and knowledge, and the way in which the activities are organised. Tools are technical devices as machinery, hand tools, buildings, etc. - equipment that in economics are labelled as real capital. The labour is not only the physical power of human beings but particularly their skills and knowledge provided by their individual and social experience and by research and development. Skills and knowledge pertain to the ways in which the tools are effectively used in correspondence with material and labour. Organisation of the activities, however, pertain to the social framings in which the productive activities are carried out besides the relations between the elements included in the productive activities. Putting this into an actual approach seen from a social point of view implies the necessity to understand technology as consisting of three elements:

- Technical devices,
- Skills/knowledge, and
- Social organisation

So, technology is related to technical matters considered in the social context; the latter being the social framings in which techniques and tools are applied and organised. In this sense technology is dealing with social organisation of productive activities and the inclusion of nature in these. In this sphere it is also determined whether the productive activities are sustainable. That is so because it is in the social organisation that the interplay between human activities and natural life support systems is determined. Just one step further is needed in the investigation of technology to underline that point.

Figure 2



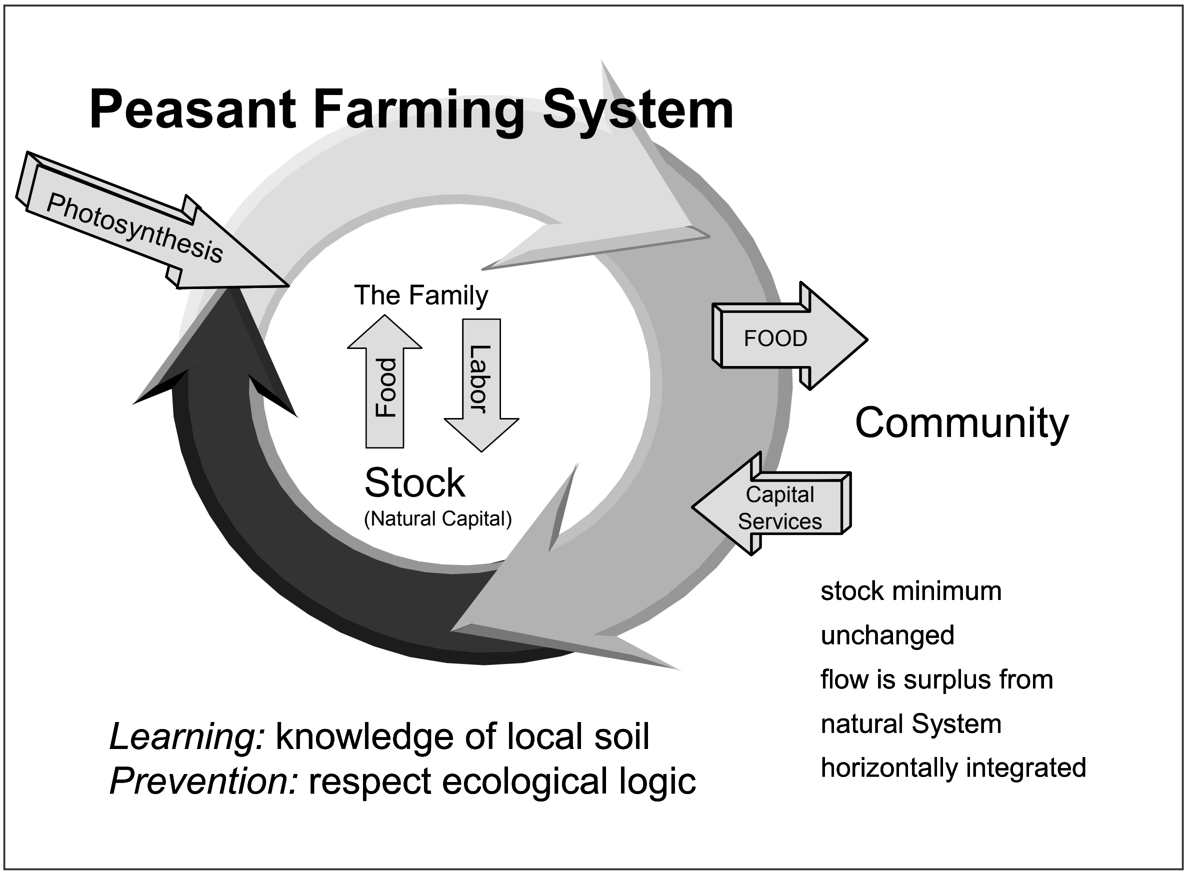
The material structure in which the productive activities are carried out consists of two main parts: those made by nature and those moderated by man. Both are necessary conditions to carry out social production; for that reason social production must be based on two kinds of productive forces, i.e., the ecological and the social (re figure 2). The ecological productive forces should here cover natural capital and natural mechanisms that in unity provide the fundamental basis for human life - so ecological productive forces are the forces embedded in natural life support systems. The social productive forces - embedded in societies - should here cover the human performance by means of labour and real capital. It is important to underline that the working capacities involve a physical dimension (the labour of hands) and a mental dimension (the labour of mind) - the latter for instance the ability to co-operate and learn, cognisance, etc. The latter dimension could also be labelled as human resources. Among the two productive forces, the ecological is claimed to take precedence over the social due to the obvious fact that the ecological forces can exist (i.e., produce and be reproduced) independently of the social forces while the opposite situation is impossible. The ability of the social productive forces to produce and reproduce is fatally depending upon the ecological forces regarding both natural capital and natural mechanisms. The human reproduction (for the individual as well as for the species) is for instance only possible by means of biological mechanisms; at the same time construction of real capital is only possible by means of natural resources converted by means of human labour. As individuals, society, and species we therefore bear a fatal interest in and responsibility for maintaining the natural capital and avoiding damaging intervention in natural mechanisms when we carry out productive activities. Although the social productive forces rest upon the ecological, we have of course to be careful and bear forethought in our use of social productive forces, too. (Ingemann, 2001b)

Agriculture and the environs - a historical illustration

From the comments above follows that technology (and then human interplay and exchange with natural life support systems) both affects and depends upon social environs. To introduce fundamentally new technologies it is necessary to alter the institutional and structural design of society. When the social design is altered rigidity occurs in a new epoch and tends to keep technological evolution locked in the new direction and evaluated against the new rationality. This interdependence between technology and social environs will be illustrated below by means of a brief historical sketch.

The peasant production system went through changes when conversion into livestock production took place in several countries around the year 1900. However, the applied technology was still founded so that the farm constituted an ecological unit part of a local and transparent cycle including livestock and grain production using very limited external inputs. This system (as illustrated in figure 3) implied a high degree of farm self-supply in relation to energy and raw materials. It implied a certain consciousness, too. The transparent reliance and dependence upon natural life support systems did provide the foundation for a cyclical common notion of nature as well as of society. This notion was often explicitly stated as a comprehension concerning property rights of future genera-tions: the soil should at least be passed on to the next generation as fertile as received from the past. Basis for this comprehension was experience and knowledge; if the farmer managed his livestock or soil contrary to the biological logic of ecological cycles he would experience negative productive reactions from both livestock and soil. These negative reactions would further result in negative economic performance and then economic pressure on the family. Shortage of material opportunities could of course force the families to act as short -sighted and then to ignore long term considerations. However, without romanticising the past, one can conclude that in those times farming technology was ecological; and a functional integrity was maintained between labour (often the farmer and his family) and the local natural life support system.

Figure 3

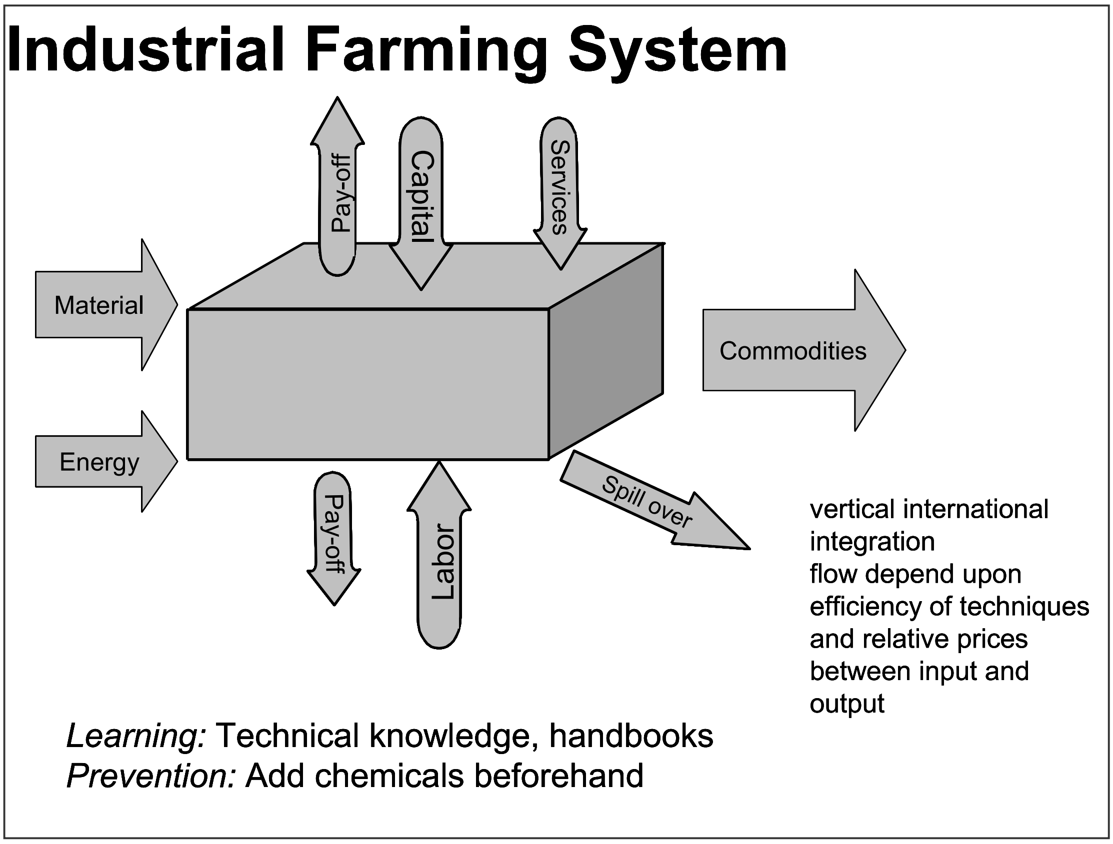


The surplus from the ecological cycle - produced by means of photosynthesis, labour, and natural capital (primarily soil) - could be exchanged with the external economy. However, for a major part this exchange took place at the local level implying a relatively close relationship between the producer and the consumer - in other words, the social cycle, too, was transparent and rather horizontal. This implied that the consumer could personally experience the ecological cycles, while the farmer could face the consumer and receive reactions from the latter concerning the food supplied simultaneously. This user-producer relationship was basis for a mutual understanding and for directly sharing the responsibilities attached. Similarly, the farmer could, in general experience how the potential spill over would affect the environs and how the input to his farm was provided (Ingemann, 2000).

Industrialisation of farming

After World War II industrialisation of farming was speeded up which in turn implied a rather rapid technological transformation. However, for a great part the scientific basis was already established in the mid-19th century, primarily attributed to the German chemist, Justus von Liebig (1803-1873) (Liebig, 1840). He laid down the theoretical foundation for applying chemicals in agriculture stating that the plants should only be supplied with water-soluble nutrients produced in an artificial/industrial way. In his alternative statement Liebig simultaneously and explicitly rejected the common conception of that time, which stated that efficiency of the living microbes in soil was the key to adequate and efficient farming. By means of Liebig's alternative approach the dynamic comprehension of natural life support systems - as farming was understood hitherto - could be replaced by a more clinical and industrial notion of an input-output production system. This system was designed, to a high degree, as decoupled from local natural life support systems and potentially also decoupled from local community.

Figure 4



In the mid-20th century the theoretical basis as well as an affiliated notion of decoupled relations between man and natural life support systems had thus already been offered for about 100 years. So the agricultural innovation in the mid-20th century did not reflect a new scientific but rather a new social invention. The structural and institutional framework of agriculture became transformed to enable implementation of this alternative technology quite in line with the view upon technology and in line with the current social experience of that time: the evolution of fordistic industries had prepared a general heavy increase in wealth. A structural and institutional transformation was necessary why industrialisation of agriculture implied increasing amounts produced per farm besides provision of equipment and industrial intermediates. Production and distribution of knowledge had to be altered, too, in accordance with the alternative technology and its alternative notions.

Introducing industrial technology in farming then involved a distinct break with the up to then practised relation between man and the natural life support systems besides a similar break with attached notions. According to industrial practices and notions the peasant was transformed into a specialised producer organising his production relatively detached from the ecological cycles looking upon soil as dead material re figure 4. Direct interrelation and interaction with natural capital and biological mechanisms were, to a still wider degree, replaced by technical approaches enabling an endless reiteration of similar processes on similar objects. This reiteration on similar objects implied a need to adjust the objects - fields and animals - to similarity. Simultaneously the main part of the necessary inputs was reached outside the local ecological cycle and then outside the local natural life support system; for instance energy and industrial raw material. Besides, the application of various chemical inputs, such as pesticides and antibiotics, implied that biological indications of mistreatment were missed. Indications such as crop rotation and livestock diseases were no longer interpreted as symptoms of the farmer's inadequate knowledge and experience but as inevitable parts of production. According to the new approach such symptoms should just be cured through appliance of systematic - most often chemical - treatment. Finally, the detachment involved a new demarcation between crop and livestock production by which manure tended to be interpreted as troublesome waste and not - as hitherto - as a valuable and integrated element in an efficient symbiosis between livestock and soil.

Thus, the cyclic ecological relation between man and nature was replaced by a linear relation where to a certain extent, agriculture, became detached from living biology and interpreted and organised as an iterative production process to a certain extent; input at one end and output at the other. Nature then became an outdistanced object and the functional integrity between man and nature tended to disappear. The conversion also implied new fields of experience whereafter human learning about agriculture and natural life support systems changed. Where the peasant of the past experienced that actions adverse to basic ecology (knowledge about fundamental principles of cycles in nature) would give a negative pay off, the modern farmer experienced that actions adverse to industrial logic would give a negative pay off - for instance if he avoided pesticides. Certainly not because the nature or the logic of its fundamental mechanisms was transformed, but because the social institutions and structures around agriculture were so.

Supplementary the industrialisation caused a decoupling from the local level, whereafter inputs were provided from industries around the world and the farmer lost the breath of view of the interrelated connections his farm became part of. Thus he lost insight into the production of his inputs and the subsequent dependence on natural life support systems in various parts of the world. Farmers' horizontal integration was then replaced by vertical, international integration where the individual farmer became a tiny part in an international system hard or impossible to take in. This internationalisation also implied that farmers tended to be separated from consumers, who became spread all over the world and then became rather invisible. Governmental institutions took over responsibility for the veterinary quality and should thus secure that consumers did not catch diseases from eating the food - the personal user-producer relationship then disappeared. Similarly, spill over - for instance pesticides - from farming seemingly disappeared out in nowhere whether these occurred on the farms providing food to the processing enterprises or on the farms in other parts of the world producing produce as input to the former farm. (Ingemann, 2000).

Observations about post industrial society and its present capability to redirect the trajectory towards sustainability

Over the past decades, an increasing awareness has been dawning in the so-called developed world that sustainable development is necessary to alleviate local, national, and global problems afflicting the natural environment. It is suggested that this acknowledgement can be understood on the background of changes in values (related to mass belief systems) that can be attributed to the transition from an industrial to a post-industrial and post-material epoch in our rich part of the world (Inglehart, 1997). It is further suggested to be seen as a consequence of experiences with the irreversible and fatal environmental effects that modern technologies can result in (e.g., World Commission, 1987; Walter, 1999).

The post-industrial responses to the awareness about human misuse of natural life support systems have so far been of three kinds:

1) Several local, national, and global meetings supplemented by an endless stream of documents.
2) A marginal number of green consumers and producers trying to do something in delimited sectors like renewable energy and organic food.
3) Governmental regulations *after* natural life support systems have been damaged.

To put it polemically the comments on the reactions could be:

1) Words do not make a sustainable technology. It is not by means of words but by means of actions we poison our drinking water and damage the ozone layer.
2) We do not turn society into a sustainable trajectory by eating an organic roast on Sundays and junk food the rest of the week.
3) We do not reach sustainability if we keep on fighting symptoms and leave the fundamental causes unaffected.

This is, of course, an unfair and derogatory judgement. The efforts made by grass root activists and well-meaning politicians and bureaucrats ought not to be underestimated - they represent essential social actors. However, the polemic characteristic brings forward the crucial point: a more comprehensive and fundamental modification of behaviour towards sustainability has yet to be attained. This is the case although most of us presumably know - and many of us obviously know - that a good deal of our actions are not sustainable; but with the current institutional framework and the social structures within which we act, we can hardly do otherwise. Of course, as an individual I can modify parts of my daily actions and routines; I can even opt out and move to an uninhabited island and live my life in harmony with nature. However, none of these options fundamentally affect technology because the latter involves *social* organisation and then is a social matter only to be transformed by means of social decisions and collective actions.

The comprehensive modifications of behaviour have fundamental changes in social structures and institutions as a prerequisite. One of these changes is re-establishment of rural-urban co-development founded on a conscious recognition of the basics of natural life support systems; under here it is necessary to recognise that urban areas have evolved as heterotroph without adequate linkages to recipient technologies in rural areas. From a social point of view such points call for a new design of social structures and institutions where regard for function and capacity in natural life support systems is couched in the basis for the social rationale just as is the case with democracy and human rights. By the way, who would, for instance, seriously calculate whether the monetary benefits in current prices would exceed the monetary costs if we abandon freedom of speech?

Concluding remarks

It is asserted above that a new institutional and structural design of post-industrial society is an urgent task if serious threats to human prospects should be avoided. To gain such sustainability, respect for the ecological forces of production is a prerequisite. On the other hand it is also necessary to recognise that the purpose of society's productive efforts is to meet human needs *and* in fulfilling that task, the social forces of production are a prerequisite, too. Thus we must consider two productive forces and two allocation systems related to human production and then to technology. An allocation system exists within natural life support systems that is independent of man. Due to technology and the ensuing production, humanity has introduced its own supplementary system of allocation (economy within politically established frames). The human allocation system has implications for the ecological forces of production. Ecology concerns the allocation and circulation of matter in the environment, while economy concerns society’s allocation and circulation of exchange value between citizens. Both ecology and economy are realities that are necessary for human production and reproduction. So, we can neither abolish ecology nor economy. Conversely, we can change the institutional and structural framings for the economy and so, politically determine society’s trajectory.

Hence, the challenge is to design social institutions and structures so that they escape the current mismatch between the two necessary allocative systems: ecology and economy. This is as far as we can get by now, because we are only equipped with a vague sense of what that design actually should entail when carried out in practice. So it is claimed that no one - for the time being - has a final recipe. Thus, the necessary knowledge and experience must be produced. We can use inspiration from the past - for instance acknowledge lessons from the peasant system as introduced above and as included in the *principles* of organic farming. But we cannot turn the clock backwards and return to previous trajectories, and if we could why then abandon progress that humanity all has after endeavoured in the time between now and then?

The proper and adequate solution is to carry out social experiments to produce the necessary knowledge and experience concerning institutional and structural design of sustainable technology in a post-industrial society. In this connection it must again be remembered that technology consists of both technique and society’s organisation, and that sustainability involves the relationship of technology with the ecological forces of production. Sustainability is therefore not necessarily synonymous with substitution of existing techniques - we do not necessarily have to wait for new inventions and innovations on the technical level. Evolving *organisation* of society, which is the other dimension of technology, can advance more sustainable utilisation of the ecological forces of production, even in the short-term and with the continuing adaptation of existing error-friendly[2] techniques. Here it should also be remembered that or-

2 Error-friendly technologies are characterised by reversible and transparent effects on the environment (Weizsäcker and Weizsäcker, 1984).

ganisation of society includes the relation between rural and urban activities.

In Denmark, Ecological Experimental Areas (EEAs) are suggested as a means to carry out the necessary experiments. EEA are geographically specified areas where communities can conduct experiments concerning the means by which not only delimited subsectors but an entirely sustainable society can evolve. It is pointed out that the EEAs must be founded in existing communities because the aim is to explore how present society can evolve institutions and structures supporting sustainable technology as an entire and consistent system able to produce and reproduce. Furthermore, basis in existing communities implies experiments concerning both the process and the substance. The *process* because the findings will indicate how to evolve society from the present stage to a sustainable stage. The *substance* because the findings will indicate how to design social framings that enable a sustainable interplay between the ecological and economic allocative systems. (Ingemann 2000b; Ingemann, 2000c)

If such experiments are to be meaningful then they must, naturally, have a high degree of freedom to gain experiences via trial and error. Indeed, they must be empowered to extricate from the current social framings that are the cause of present mismatch and social traps (Costanza et. al. 1998). But it must be maintained, nevertheless, that it is an indispensable objective for the experiments that they must seek a suitable design of society that promotes sustainable technology in a post-industrial society. In the design of institutional and structural framings for zones as EEA it is then of fundamental importance that the ecological forces of production are consciously reintegrated, and that one is deliberate about procuring the necessary empowerment to avoid social traps.

Delimited sub-technologies such as organic agriculture and renewable energy are developed with matching partial conceptions and stand together with historical inspiration available for the experiments. The challenge is to connect these delimited sub-technologies in interaction with, and with the utilisation of, other relevant technological conquests for entire systems of human production and reproduction. In this connection it is also necessary to carry out adaptations, changes, and the further development of these conquests.

However, knowledge and experience presented at this seminar will form a mosaic that can be useful to the practitioners who must carry out social experiments on our behalf in an attempt to find the way in which rural-urban co-development can be established as sustainable technology.

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The embeddedness of local food systems

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Introduction

In a questionnaire survey carried out in Southern Sweden (see Vergunst (2001) for a description of the method), approximately 100 respondents were asked whether they considered it important that their food comes from the region where they live. Two thirds of the respondents answered positively. However, equally many respondents did not consider it possible to live on regional food supplies only. Moreover, half of the respondents were not aware where their food came from at all, whereas about one third of the respondents expected that between 0 and 24% of their food consumption was regionally produced. The freshness of the product, and the price, are major criteria for the choice of products for the respondents, with the nutritious content and the region where the food comes from only being important to a minor extent. On the other hand, EU regulations and subsidies and the economy are considered most important. When it comes to what will be produced in a certain region, farmers and foresters are assumed to have less control of this question, with consumers and stakeholder organization having least power.

What do the findings of this questionnaire actually mean? Do they tell a story about decontextualization of our food system? Does this story address the (assumed) power of policies and the market, whereby producers and consumers have lost their sense of control? Is it true that, as a consequence of the latter, consumers have lost faith in the fact that their own region can produce the food they need? Do the findings of the questionnaire reflect reality as it is constructed in the minds of consumers? Is also another reality possible?

The global food system

In this paper the global food systems is characterized by what can be considered as the conventional production chain. In this, farmers attract their agricultural inputs from industry, at the same time as their products leave the farm as raw materials that form the input for the food industry (Friedmann, 1993). This production chain is dominated by food industries and large supermarket chains (Pretty, 1998). The global food system is rational, centrally planned, and efficient. It is concentrated in a small number of large, vertically integrated multinational companies that seek control of production, market share, and profits on a global basis (Grey, 2000).

The word 'global' in the global food system refers to the fact that food security is approached at the global level, whereby all parts of the world are considered highly dependent on each other. Land use is specialized (Kloppenburg et al., 2000), the principle of comparative advantage determines where products are to be produced (La Trobe & Acott, 2000). As a consequence, trade is a condition for the functioning of the global food system. Abstract powers and money (capitalism) seem to be the major source of control. It is economic and political forces that, to a large extent, determine what is to be produced where. The global food system might be understood in terms of Habermas' uncoupling of the system and lifeworld. The mechanisms of the system – money and power – steer a social intercourse that has been largely disconnected from norms and values. Social relationships – the lifeworld – have become more and more regulated by money and power (Outhwaite, 1996). Hence, what Habermas actually refers to is the widening gap between, on one hand the bureaucratic system and market and, on the other, everyday life, leading to decontextualization and alienation.

The global food system can further be characterized by its vulnerability. Redundancy refers to the quality of state of being redundant, i.e. the superabundance, whereby not all information is necessary to sustain the total system (because of excess of information). Its lack of redundancy makes the global food system vulnerable. As the global system goes towards producing food in regions where the natural and economic conditions for particular crops and livestock are best, many areas of the world are characterized by monocultures, whose products are to be traded around the world. If a crisis emerges in one part of the world, it consequently affects food security in other parts of the world.

Local food systems

In this paper, the term, local food systems, is used to refer to new, consciously formed systems, which are characterized by close producer-consumer relationships, i.e. farmers having direct contact with consumers (Vergunst, 1999). To the extent that local food systems encompass small-scale processing industry and shops, these stakeholders are less powerful than in the global food system.

As food security is pursued at the local level, the local land use system is diversified (Kloppenburg et al., 2000), produces all basic foods for the people in the locality. As a result of different biophysical and ecological conditions, local land use systems are different in different parts of the world (Vergunst, submitted 2000). In contrast to the central role of trade in the global food system trade in the local food system plays a role for adding to the food system products that cannot be produced in the region (Vergunst, submitted 2000). This inability may be due to unfavourable climatic conditions for the production of basic foods (e.g. vegetables and fruits in areas north of the polar circle), but trade can also encompass more luxury food products that add to the quality of life of consumers (e.g. coffee, tea, and rice). The term, local, refers to the polycentricity of the system (Hinrichs, 2000; Kloppenburg et al., 2000). As there are no fixed boundaries, regions can overlap (Vergunst submitted 2000). The term local emphasizes proximity (Kloppenburg et al., 1996) rather than a certain size of the area. At first look the local food system seems to be subjectively controlled; communication between producers and consumers (Vergunst, 1999) seems to be the most powerful tool. As a consequence, local food systems might be perceived as an attempt to relink the system and the lifeworld (Vergunst, 1999).

An alternative kind of global food system consisting of a myriad of local food systems is more prone to be redundant than the conventional global food system. As local food systems aim at some degree of food security at the local level, the global system is less vulnerable. In case one local system is in crisis, other local systems are not necessarily affected.

The co-existence of the global and local food systems

Taking a closer look at reality we can observe that there are regions that have more or less maintained their traditional food systems, just as we notice new local food systems emerging at the same time as the speed of the globalization process of the global food system increases. Globalization does not have a uniform impact everywhere. In fact, it has generated a whole diversified pattern of responses at national, regional, and local levels (Long, 1996). Implicit in this is the understanding that local food systems will emerge within the global food system, within it is changing. In reality localization takes place at the same time as globalization processes continue. Long (1996) refers to this as re-localization, i.e. the resurgence of local commitments and the reinvention or creation of new local social forms that emerge as part of the process of globalization. De Haan (2000) talks about glocalization, i.e. the trend towards global markets and politics, at the same time as the importance of regionalism and community increases.

As we have seen, local food system are reconnecting the system and the lifeworld and through that able to relink people to their place. In addition, local food systems are less vulnerable than the global food system, i.e. more redundant. The question dealt with in this paper is how we should understand the economic functioning of local food systems. Is our neoclassical economic conceptual framework enough to understand the economic functioning of local food systems or do we need another economic understanding? What follows is based on an analysis of literature on a variety of local food systems, as well as on experiences of the researcher herself. In this, the researcher is explicitly assumed to be part of society whereby theoretical analysis are nuanced the with help of experiences of personal involvement in a local food system, and of discussions in various media.

The economic paradigms underlying the global and local food systems

How should we understand the economic functioning of local food systems? To answer this question, the hypothesis that most economic behavior is closely embedded in networks of interpersonal relations (Granovetter, 1985; Plattner, 1989) as opposed to the impersonal/atomized relations in the global food system, is tested. To do so, three approaches to the local food system are worked out: flows of feedback, Habermas' instrumental and communicative rationality, and Mongione's R(eciprocity)A(ssociation) M(arket) -triangle.

The analyzed literature deals mainly with different types of so-called close producer-consumer relationships: community-supported agriculture, vegetable box systems, and farmers' markets. These close producer-consumer relationships can be regarded as examples of institutional forms of local food systems.

Flows of feedback

Individuals and social groups are in interaction with their environment. They are neither powerless objects nor free agents who can become whatever they choose. There are feedback loops among actors themselves and between actors and the context in which they live (Haan, 2000). Feedback is the transmission of information about actual performance to an earlier stage in order to modify action (Checkland, 1986). However, it may be questioned whether the feedback loops in the global and local food systems are not qualitatively different. Feedback assumes perception and interpretation (Röling & Jiggins, 2000). This can be understood with the help of Kolb's learning cycle (Wolfe & Kolb, 1984), which begins with the learner having a concrete experience, on which he or she reflects. He or she then engages in abstract conceptualization by creating generalizations that integrate these reflections into theories. These generalizations and hypotheses are then tested in more complex situations, though action (King, 2000; Wolfe & Kolb, 1984). Kolb's learning cycle is assumed to be a powerful model to explain the different outcomes between situations where feedback loops are different in quality and quantity.

Two types of feedback can be distinguished: negative and positive ones. Negative feedback loops keep systems in equilibrium (Norgaard, 1994), as they reduce the difference between actual and desired performance (Checkland, 1986). Any negative feedback loop needs a goal, a monitoring and signaling device to detect excursions from the goal, and a response mechanism. The strength of a negative feedback loop is important relative to the impact it is designed to correct. If the impact increases in strength, the feedback has to be strengthened too (Meadows, 1997). Positive feedback loops are self-amplifying, explosively driving some variable in the model to infinity or implosively to zero. Hence, positive feedback loops lead to disequilibrium (Norgaard, 1994). As positive feedback loops are self-reinforcing, a system with unchecked positive feedback ultimately will destroy itself (Meadows, 1997).

The analysis of the literature demonstrates that there is a major difference in feedback flows as they occur in local food systems, as compared to those in the global food system. The global food system is characterized by an almost linear flow, constituted of a flow of products forward in the food chain, for which the provider gets money in return. The local food system justexposes the traditional linear means of moving food from farmers through a complex system of marketing processing, packaging, and selling with the idea that all members participating in the local food system are intricately linked in a web of connections (Hendrickson, 1997). In local food systems, feedback flows are much richer and can be characterized as cyclic in stead of linear (Eksvärd et al., submitted 1998). In the following alineas a short description of these rich flows will be given.

In local food systems, the flow from the farmer to consumers consists of three aspects. First, there is the exchange of food (Fieldhouse, 1996), which is contributed qualities of organic and high quality (Deane, 1996). Second, there is information flowing from the producer to consumers (Marsden et al., 2000), e.g. in the form of a newsletter in a vegetable box system (Deane, 1996), or through on-farm activities in the CSA (Cone & Myhre, 2000). Third, there are immaterial qualities attributed to these flows of food and information, such as the food being added the aura of personal relations (Cone & Myhre, 2000; Hinrichs, 2000) and eaten with satisfaction (Deane 1996). Finally, in the case of the CSA, members feel being included in the process of growing food, and through that they feel more connected to both the food systems (Fieldhouse, 1996) and the natural environment (Kolodinsky & Pelch 1997; Marsden et al., 2000).

However, there is also a rich flow from the consumers back to the farmer. First of all, as is the case in the global food system, the farmer gets money in return for the food he produces. However, in the case of the CSA there is also a sharing of the risks of farming (Cone & Myhre, 2000; Fieldhouse, 1996; Hinrichs, 2000; Kolodinsky & Pelch, 1997) and through that the farmer enjoys increased security of a predictable income (Deane, 1996). In addition, a CSA-farmer can draw upon help of the members of the system (Cone & Myhre, 2000). Generally, through close producer-consumer relationships the farmer also receives immediate response to the food he produces (Holloway & Kneafsey, 2000). Finally, as is the case in the flow of producers to consumers too, the farmer experiences immaterial qualities such as increased job satisfaction (Deane, 1996), personal relations with a group of consumers (Lyson et al., 1995). Moreover, in the case of e.g. farmers' markets, it is mentioned that farmers enjoy these for being a social event (Hinrichs, 2000; Holloway, & Kneafsey, 2000).

Habermas' rationalities

Habermas uses the term instrumental rationality to introduce the concept of communicative rationality. In instrumental rationality one follows technical prescriptions in order to achieve previously defined goals. Other actors are treated as objects whose behaviours follow some empirical laws and rules (Eijk, 1998). Instrumental rationality can be characterized as the belief in technology and the control of the biophysical environment (Röling & Maarleveld, 1998).

In communicative rationality actors aim at coordination of their activities through consensus on a common definition of the situation (Eijk, 1998; Outhwaite, 1996; White, 1990). They pursue their goals under the condition that they can harmonize their plan of action on the basis of a common understanding of the situation. Reaching understanding is considered to be a process of an reaching agreement which has to be accepted as valid by all participants (Outhwaite, 1996).

In contrast to the global food system, where instrumental rationality is assumed to dominate, there seems to be another balance between instrumental and communicative rationality in local food systems. Hinrichs (2000) is one of the authors directly arguing for this, when she states that the familiarity and trust between producers and consumers does not necessarily lead to a situation where price is irrelevant or where instrumental interests are completely set aside. Lyson et al. (1995) argue for a similar balance, as farmers' markets occupy social spaces in which formal market transactions are conditioned by local community norms, values, and culture.

Partially as a consequence of the fact that the literature on local food systems tries to demonstrate the special properties of close producer-consumer relationships, and of the fact that a large proportion of the literature seems to describe an ideal situation, rather than practice, much of the literature emphasizes aspects of communicative rationality. According to Kloppenburg et al. (2000) a sustainable food system is one in which people directly participate in the operation and governance of multiple components of the food system in ways that are more influential than simple market transactions. Enhanced participation in the food system implies becoming activated as a citizen-eater, i.e. someone who is involved in democratic decision-making processes. A sustainable food system is one in which farmers, consumers, processes, and other participants have relationships either through direct contact an/or through networks emphasizing responsibility, communication, and care for each other and the land (Kloppenburg et al., 2000).

Especially CSA and vegetable box systems seem to be based on a common understanding of both the farmer and the consumers that is a result of direct communication. In CSA, the paying of a share before the start of the growing season in return for a weekly share of food can be interpreted as being based on a common understanding. Though the farmer and the consumers benefit in different ways from these relationships, the solution is valid for both parties.

Farmers engaging in direct relations with consumers often communicate directly with consumers (Deane, 1996; Fieldhouse, 1996). A newsletter accompanying vegetables boxes, e.g., promotes a greater understanding among the subscribers (Cone & Myhre, 2000; Deane, 1996; Powell, 1995). Both Murayama (1996) and Fieldhouse (1996) talk about joint planning activities. In general, it is argued that in local food systems, cooperation is needed between all stakeholders, both urban and rural participants need to invest in their food system (Cone & Myhre, 2000; Feenstra, 1997).

To a lesser extent aspects are mentioned that point at instrumental rationality. From a consumer's perspective a competitive price is needed (Feenstra, 1997), shareholders want to get their money's worth (Cone & Myhre, 2000). Holloway & Kneafsey (2000) emphasize the importance of farmers' markets as being a real alternative to wholesale/contract market for especially small and medium-sized growers producers, as higher profit margins can be obtained there and because of a reduction of costs.

In all, it can be argued that in addition to instrumental rationality, communicative rationality plays a role in local food systems. These two types of rationalities can be envisaged as a continuum with instrumental and communicative rationality being the two poles. The exact position of this continuum is, amongst other things, dependent on the type of close producer-consumer relationship, whereby the characteristics of stakeholders, the length of the production chain, and the kind of products involved play an important role.

RAM-triangle

Grounded in the work of Polanyi, Mingione distinguishes between three basic forms of social relations of exchange: market-competitive behaviour, reciprocity and redistribution (Mingione, 1991). Market-competitive behaviour only makes sense if it is assumed to operate free of any socio-organizational constraints, while reciprocity and redistribution are meaningful only within forms of social organization. Market exchange makes sense as an abstract concept only if it is perceived as a finished transaction taking place between actors who are unaffected by other kinds of established social relations. Reciprocity is a form of exchange based either on delayed or eventual restitution, or on redistribution to somebody different from the actual donor. Reciprocal exchange depends on a set of established socio-organizational network which fix the rules as to who gives and who receives, what is given, and at what time. Similarly, redistributive exchange does not make sense beyond the existence of established relations and rules that determine what resources are taken from the direct producers for redistribution, to whom they are allocated and in what ratios, and also who does the taking and for what reasons (Mingione, 1991).

Aarsather & Baerenholdt (2000) refer to the RAM-triangle that highlights three types of social relations: reciprocity, associational (redistributional) relations, and market relations. They then hypothesize that localities where these three types work in concert will be more viable than localities in which only one or two of these forms dominate (Aarsaether & Baerenholdt, 2000; Baerenholdt & Aarsaether, 1998). This does not mean harmony. Conflicts and tensions are envisaged, because the three forms of social relations are constructed on very different principles, ranging form affective and emotional bonds (reciprocity), the principle 'one person - one vote' (associational), to agreement on price, based on private property and economic efficiency (market relations) (Aarsaether & Baerenholdt, 2000).

Also in the case of the RAM-triangle it could be argued that in local food systems, market relationships are added by reciprocal social relationships. The exact place where the different close producer-consumer relationships find themselves in this triangle is dependent on the type of relationships between the farmer and consumers. Trust, the expectation that arises within a community of regular, cooperative behaviour, based on commonly shared norms (Svendsen & Svendsen, 2000), is an important aspect of reciprocity, which is reflected in the literature analyzed. In CSA the share symbolizes the members' shared acceptance of the risks farmers assume in farming and the members' willingness to subordinate their own economic interests (Cone & Myhre, 2000; Hinrichs, 2000; La Trobe & Acott, 2000). Hence, the CSA-share is an economic transaction sufficed with trust (Cone & Myhre, 2000; Hinrichs, 2000; Powell, 1995). Impersonal exchange is replaced by relationships of trust. However, trust in local food systems might also be generated because of the confidence in a known social structure, rather than in individuals whom we know (compare (Pretty & Ward, 2001)).

Discussion and conclusion

This paper dealt with the comparison between global and local food systems, whereby the local can be perceived to co-exist with the global. The global food systems is centralized and grounded in the neoclassical economic paradigm, local food system are polycentric (Imperial, 1999; Olsson, 2000; Ostrom, 1998), whereby economic relationships are embedded in social structures. This embeddedness cannot be generated in the global food system, as it is because of the small-scale communities with face-to-face interactions, which constitute the local food system, that trust is established (compare (Falk & Kilpatrick, 2000; Svendsen & Svendsen, 2000)). This paper illustrated that in local food systems there is a complex network of negative feedback loops, aiming at the reduction between actual and desired performance. In addition, do the global and local food systems take different positions on the continuum of the instrumental and communicative rationality, as well as on the continuum of market and reciprocity. While the global food systems is characterized by the poles of instrumental rationality and market, local food systems - depending on the type of close producer-consumer relationships - can be placed, to a larger or minor extent, closer to the poles of communicative rationality and reciprocity. As these two economic paradigms co-exist, they create a reality which is greater than the sum of each (Midmore, 1996).

However, the concept of local food systems should be described more precisely. First of all, there are close producer-consumer relationships where basic food products are exchanged. Nevertheless, this same economic structure can be used for the exchange of niche-products, and there are local food systems in which value is added to raw materials on-farm. The two last-mentioned are examples of what can be non-basic food products. Adding value on the farm can also take place to generate niche-products or for being able to reach a wider market for processed products. In the latter case, I would like to argue for this being embedded in the neoclassical economic paradigm, as criteria as distance and durability (Friedmann, 1993) play a major role. Related to this difference between the generation of basic food products and niche-products is the contradiction between authors arguing that local food systems mainly benefit the richer people in society (e.g. (Holloway & Kneafsey, 2000)) and authors arguing that local food systems are a powerful method for poverty alleviation (e.g. (Feenstra, 1997; Pretty, 1998)). Richer people may benefit most in the case of niche-products, poor people may be referred to in case of the generation of basic food products.

Another critical factor that has to be addressed is the kind of close producer-consumer relationships we talk about. In contrast to CSA and vegetable box systems that are based on the principle of direct contact between producers and consumers, there are also delivery systems coordinated by middlemen, such as food cooperatives (Marsden et al., 2000; Powell, 1995). The latter-mentioned systems might reach so large a scale that they are based much more on pure market relations than on trust, and can thus be placed on the market-relations side of the RAM-triangle. In this paper, however, the term, local food systems, is used to refer to local systems, where producers, processors, and consumers live in the same area in which basic food products are exchanged locally, and in a sphere of personalized relationships. From a systems thinking perspective the flows of information and immaterial feedback flows between producers and consumers, as well as the importance of trust can be perceived as the emergent properties of local food systems.

As mentioned before, it is assumed that the global food system coexists with local food systems. What we observe is that, in reality localization takes place as long as globalization processes continue. It is Long (Long 1996) who refers to this phenomenon as relocalization, i.e. the resurgence of local commitments and the reinvention or creation of new local social forms that emerge as part of the process of globalization. But how can this be explained in economic terms? First of all, it is important to recognize that the neoclassical economic paradigm is but one way to organize society. As we have seen in the case of local food systems that coexist with the global food system, there are also other ways. However, the neoclassical economic paradigm is infiltrated in all parts of society. Many people are probably not even aware of the fact that it is that paradigm that lies underneath the structure of the global food system. The neoclassical economic paradigm is often treated as objective. The way in which people understand the world is always subjective. Each theoretical perspective focuses on certain phenomena at the expense of others. Truth is partly a matter of ideology (Söderbaum, 1999). Only a situation of simultaneous coexistence of theoretical perspectives in economics appears to be a solution (Söderbaum, 1999). There are different types of value and it would be misleading to take decisions on only one type of value (Funtowicz & Ravetz, 1994; Martinez-Alier et al., 1998). Recognizing conceptual and theoretical pluralism should heighten our awareness of the structure and assumption of diverse conceptual frameworks through appreciation of their differences. To accept this pluralism is to accept multiple insights and the inherent ability of science to describe complex systems consistently, to predict how they might behave, or to prescribe how to make them behave in another way. If science, as it is conventionally understood, provides fragmented, incomplete insights at best, whatever understanding we have of whole systems are synthesized by some other process than what has hereto been understood as science (Norgaard, 1994). In all, to understand the complex reality of local food systems emerging within the global food system, it is necessary to make use of conceptual pluralism.

This coexistence of global and local food systems can also be linked to theories of dual economies (Douglas & Isherwood, 1978; Hornborg, 1998; Hornborg, 1999). In this respect, Hornborg discusses the possibilities of local currencies for subsistence and short-term reproduction (the local food system), and a global currency for telecommunications and long-term social projects. The primary objective with such a distinction between local and global currencies should be to inhibit exploitative exchanges of labour time and natural space between local ecosystems (Hornborg, 1999). Douglas & Isherwood (1978) describe the separate economic spheres of the Yurok in California. Here, there is a sphere of political goods, substitutable for each other at standard exchange rates, and a sphere of domestic goods and services that are freely exchangeable for each other. Whereas the former are low-frequency transactions involving large social units, the latter involves high-frequency transactions within small social units. In fact, it can be argued that the existence of local food systems within the global food system can be perceived in terms of general and special purpose money. The economic paradigms on which these two systems are based are not compatible. Whereas in the global food system instrumental rationality dominates in pure market exchange relationships, in local food systems, there is a different balance between instrumental and communicative rationalities, whereby reciprocity – trust – plays a decisive role. Plattner (1989) talks in this sense about the distinction between embedded and atomized exchange. Whereas personalized or embedded transactions are between people who have a relationship that endures past the exchange, impersonal or atomized relationships are not organized in social structures. In all, the global and local food systems can be regarded as dual economies, whereby the global food system is characterized by general-purpose money, while local food systems employs personalized special-purpose money that is based on trust, and that cannot be exchanged between localities. The local food system therefore generates redundancy to the global system.

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Impact of Production Method and Production Area on Energy Balance of Rye Consumed in Helsinki

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Abstract

The aim of the study was to find determine the impact of production method and production area when evaluating energy consumption in life-cycle analysis of rye. It is assumed that transportation and fertilizer production are the most important energy consumption factors in grain production. This study attempts to find out the importance of all the different factors which are involved in the energy consumption in rye production. The object of study is rye consumed in Helsinki.

The results of the study show that production of fertilizers is the biggest factor in the rye production chain. Therefore organic rye tillage is not as intensive in energy usage as conventional practices. The difference between these two alternatives is almost 50% when rye is cultivated in Finland. The third alternative in the study was rye produced in Germany, as part of the rye consumed in Finland is imported. The German rye was clearly better than the Finnish one when the criterion is energy consumption, but not as good as Finnish organic rye. The energy consumed for transportation does not play a big role in total energy consumption of rye consumed in Helsinki. For that reason and due to good cultivation conditions in Germany, the need of energy is higher per unit of rye produced in Finland than for imported rye.

We can see that in Finland the use of energy input in agriculture should be improved. The biggest opportunity for this is the movement for organic cultivation. On the other hand, the use of non-renewable energy sources should be replaced by the use of renewable energy production, for example in grain drying. Then the negative effects of energy use would be decreased and Finnish rye could be more competitive measured by energy accounting when compared to other production possibilities.

Index words
crop, ecological economics, energy balance, food system, rye

Introduction

Agriculture and food production industry have been very important factors in societies like Finland which have been concerned about for example the availability of food due to a crisis because of a political and geographical situation. For that reason the food sector has been largely regulated and domestic grain production has been a truism. Such a policy has been very expensive and caused overproduction problems (Spedding 1996, 17).

When Finland joined to the European Union also agriculture had to face the competition because it became possible to import grain. The globalisation of the food sector is a reality. Because of that the importance of price of grain production is usually very high. It is also quite easy to move food supplies from on country to another.

The global food system[1] tends to be very energy-intensive. One important energy user is transportation which uses mainly fossil fuels. There are many arguments for improving the food system to use less energy, but the main reason is to avoid negative environmental effects caused by fossil energy usage.

Because of decreasing food transportation a localised food system could be one chance to save energy. Another important possibility is organic farming. Conventional agriculture uses lots of nitrogen fertilizers whose production process requires lots of energy. In organic farming there is no need for fertilizers.

Today the energy efficiency of agriculture is not as good as before the modern technology. Although the total production per field unit has increased, farmers use more energy per unit of output than earlier (see Georgescu-Roegen 1972, Martinez-Alier 1990, Tiezzi et al. 1991). The aim of this paper is to determine the importance of the different factors when evaluating energy consumption of rye production chain and topoint out how these factors vary between different production possibilities of rye. The object of the study is rye consumed in Helsinki area.

[1] The concept of food system covers all activities linked to food production, processing and consumption. So it also has cultural, food safety and environmental dimensions.

Theoretical background

Ecological economics is a paradigm which concentrates on the relation of ecosystems and economic systems. It attempts to go beyond the limits of traditional sciences and with this synthesis to find some new insights to solve the problems. The main target is the problem, not the method. (Costanza et al. 1991, 3-6.) Ecological economics gives an opportunity to logical analysis on different interactions between societies and ecosystems (Faber et al. 1996, 12) and the main physical connections and dependence inside the economy (Christensen 1991, 80).

The main aim of an economic-ecological analysis is to develop the tools and institutions of environmental management and policy to meet the goals like economic efficiency, environmental quality, wealth of ecosystems and sustainability (Bergh 1996, 84).

A common way to approach a problem in ecological economy is **entropy.** Entropy is an index for non-useful energy in a thermodynamic system in a given moment (Georgescu-Roegen 1972, 4.) The demand of energy is always more than supply in every biological or economical process. That means that the entropy, the stock of non-useful energy has to increase (Georgescu-Roegen 1970, 54-55).

All changes in the nature or the economy require energy. Entropy is a very useful variable to describe all kinds of processes but especially the functions of economy. It is an important tool when one studies resource use and flows in an economy and their impacts on environment. The variable can be used when we describe the world, specify the problems, or try to find a common answer for problems which are linked with interactions between a economy and the nature. (Faber et al. 1996, 95-96.)

The qualitative change of energy is substantial when we study the energy use of economy. This variable can be observed by **thermodynamics**. According to the first law of thermodynamics, energy never disappears, it only changes its form (Phillipson 1970, 3). The second law, the law of entropy means that in a closed system entropy increases all the time (Georgescu-Roegen 1972, 7-8). In the economy, this shows as useful energy or raw materials turned into a non-useful form which decreases the stock of natural resources and the stability of systems (Ayres 1978, 271).

With the use of energy it is possible to recycle materials. There is also a flow of energy from the sun to the earth so, in principle, the material entropy would have not to increase. But our technology is heavily dependent on non-renewable energy sources which are decreasing according to the entropy law. So, in practice, both material and energy entropy are strongly increasing all the time.

All production systems work by the entropy law (Georgescu-Roegen 1971, 191-194). When one takes a look at materials and energy in the process the economy can be seen as a system which modifies natural resources to products and services. By physical meaning resources do not disappear. They only satisfy some human needs before altering to waste. (Ayres 1978, 289.) For example, the food system is an open system. Energy and materials flow through it. Thus, the main thing is how much and what kind of energy we need to use to get one unit of food for consumption.

Eco-efficiency is an action strategy based on quantitative input-output ratios. The aim is to maximize the efficiency of material and energy use by minimizing emissions and the use of raw materials per output unit. However, eco-efficiency alone does not give any definitions for sustainable consumption. There is still a possibility for absolute growth of production. (OECD 1997, 23-24.) One problem is also on the aggregation of different inputs and outputs together (Reijenders 1998, 16, Cleveland and Ruth 1999, 35 and 42-43). Only a material balance or energy consumption of a certain product gives no information from its total impact to environment or economic sustainability.

In this paper, the point is energy consumption of a product during its life-cycle. The solar energy utilized in photosynthesis is marked off. It is assumed that all other energy has been produced by non-renewable energy sources because that is practically true in Finnish agriculture at the moment. Therefore, we can aggregate all energy inputs used in the definite part of the food system and calculate the total energy consumption for one unit of output.

With a viewpoint of thermodynamics and biology we can see that we could minimize the growth of entropy by saving resources. For that, according to Tiezzi et al. (1991, 459), the food supply sector has to move towards decentraliz small-scale organisations which use renewable resources instead of non-renewable more than now. This is based on the thought that modern food industry is unable to use low intensity energy sources. Another reason is short transportation distances in a local food system.

The use of non-renewable natural resources is also dependent on other services of nature like the ecosystem's ability to manage emissions (Daly 1990, 4). At the moment, for example, the use of oil causes serious environmental problems like global warming, acidification, and particle emissions. Ecosystems probably cannot compensate for these emissions because of the large-scale oil use on the globe.

For sustainable development we should develop technologies which increase productivity of resources but do not increase the total use of resources (Daly 1990, 5). In agriculture this means that a grain unit should be produced by as few resources as possible. The good energy efficiency of production is very important because with modern technology almost all energy used is produced by non-renewable natural resources.

Energy consumption of rye production and transportation

In this study, there are three different possibilities for producing the rye consumed in Helsinki. The consumption place was chosen because a large part of Finnish people live on the southern coast and in the future still more people will probably live within urban food systems far away from food production areas. This underlines the importance of taking into consideration the urban areas when calculating the total energy consumption of food sector.

In this study, possible rye production scenarios are:

1. Organic farming in Finland
2. Conventional farming in Finland
3. Conventional farming in Germany

By studying these possibilities we can find the differences in energy consumption which are dependent on a production method and a geographical site of production. The study focuses on production of direct inputs, cultivation work, and transportation. The energy consumption of energy has not been observed here. The food chain ends when rye has been delivered to a mill near Helsinki. Bread processing is not included in this study.

The yield in different scenarios is the average rye yield per hectare in the years 1997-1999 (FAO 1999, 28). In Germany yields are about twice as high as in Finland and the possibility of crop failure is much smaller. In organic farming rye yields are about 30% smaller than in conventional farming (Maaseutukeskusten liitto 2000, 7). The yields used here are 1548 kg/ha for organic farming and 2211 kg/ha for conventional farming in Finland. In Germany the mean yield is 5259 kg/ha.

The cultivation practices are mainly same in every scenario. There is some variation which can be seen in table 1. Only the fuel consumption has been observed, other factors like use of lubricants are the same and quite trivial in every scenario.

In organic farming the preceding plant collects nitrogen from atmosphere and that can be used as fertilization for rye. Therefore, we have to take a part of the energy consumption of the tillage and add it to the rye calculations. This means that we add half the energy consumption of the preceding plant seeding and a consumption of hay cutting to the energy need of rye tillage. The difference between organic and conventional rye cultivation practice is 7,3 l/ha meaning that organic farming uses more energy. The energy demand of plant protection is the same for both alternatives. The total energy consumption in cultivation practices of organic rye tillage in Finland was calculated to be **77,9 l/ha.**

Table 1 The fuel use in conventional cultivation practices in Finland and in Germany

Finland	l/ha	**Germany**	l/ha
Ploughing	25,1	Ploughing	25,5
Cultivation*2	12,2	Cultivation 1	5,9
		Cultivation 2	7,8
Seeding + fertilizing	3,6	Seeding	3,3
Fertilizing	1,6	Fertilizing*2	6,9
Pesticide spraying*2	3,6	Pesticide spraying	10,9
Harvesting	13,1	Harvesting	16,0
Straw boling	2,9	Straw boling	9,1
Straw transportation	7,0	Straw transportation	8,6
Grain transportation (1 km)	1,5	Grain transportation (4 km)	5,6
		Ploughing *2	24,7
Total	**70,6**	Total	**124,3**

Source: Palonen & Oksanen, 1993

Table 2 The fertilizer usage and the sum of nutrients per hectare in conventional rye tillage

	Pellon Y7 (kg)	Suomensalpietari (kg)	**Nutrients (kg)/hectare**
Finland	214	162	70 N, 15 P, 28 K
Germany	343	204	98 N, 24 P, 44 K

Fertilizer manufacturing uses energy 15200 MJ/t (Pellon Y7) and 19200 MJ/t (Suomensalpietari)[2]. These two fertilizers are typically used in rye tillage in Finland and it is assumed that the same kind of fertilitzers are used in Germany. The total energy consumption includes fertilizers' life-cycle energy demand when the product is packed in a factory.

Nutrient use numbers in table 2 are from international statistics of fertilizer use (IFA et al. 1999) with some corrections resulting from the actual support system in Finland. Based on the calculated fertilizer usage numbers we get the energy demand per hectare **6400 MJ** in Finland and **9000 MJ** in Germany.

In Finland, there is no energy usage information available from **pesticide manufacturing.** Producers do not report any exact numbers to importers. In this study, the estimate is 360 MJ per kg effective material based on calculations of the Finnish Environmental Institute.[3] The use of pesticides per hectare in conventional grain tillage is 2.6 kg in Germany (Hoevenagel et al. 1999 ref. Oskam et al. 1997, 13) and 1.1 kg in Finland (based on total sale numbers). So, the energy demand per conventional cultivated rye hectare is **396 MJ** in Finland and **936 MJ** in Germany.

Grain has to be dried to acceptable moisture (15%). In Germany there is no need for that (Palonen and Oksanen 1993, 40) but because of the weather conditions in Finland we usu-

[2] Notification 14.6.2000. Anna Ilomäki, Kemira Engineering Ltd.

[3] Notification 6.6 2000. Juha Grönroos, Finnish Environmental Institute.

ally have to use energy for drying. In an average year, the energy demand of **grain drying** is about **1 MJ** per kg when the drier is oil heated like most dryers in Finland.

In this study, **transportation** covers all grain and fertilizer transportation outside the farm. **Loading and unloading** covers only the work done in harbours because it is the only loading variable differing between the scenarios. The transportation chains have been randomly chosen so that the distances and routes are typical for every scenario. The mill has been located at Hyvinkää, which is one of the largest mills near Helsinki. For simplicity all transportation variables which are the same in each scenario have been left out. The total road transportation distance for Finnish rye calculated in this study is 120 km. German rye travels 320 km on road and 1060 km on sea. The total energy consumption is then **0.07 MJ** per kg for a Finnish rye and **0.44 MJ** per kg for the German alternative. Loading and unloading at a harbour uses further **0.02 MJ** energy per kg when importing foreign grain. A fertilizer transportation consumes 0.09 MJ per kg in both countries which means **0.02 MJ** in Finland and **0.01 MJ** in Germany per one kg of rye product.

Results and conclusions

The summary of energy consumption per one kg of rye product in each scenario is presented in table 3.

Table 3 Energy consumption (MJ) per one kg rye product of different alternatives

	Organic (FIN)	**Convent. (FIN)**	**Convent. (GER)**
Tractor fuels	1.4	0.9	0.7
Harvesting	0.4	0.2	0.2
Fertilizers	0	2.9	1.7
Pesticides	0	0.2	0.2
Grain drying	1	1	0
Transportation	0.07	0.09	0.45
Loading & unload.[a]	0	0	0.02
Total	**2.87**	**5.29**	**3.27**

[a] Only in harbours

Based on the results of this study, we find that the Finnish organic rye consumes less energy per one kg of rye produced. The German rye consumes about 14% more and the Finnish conventional rye wholly 84% more energy than the best alternative. The organic rye tillage demands more tractor fuel than the conventional one but manufacturing of fertilizers and pesticides is so energy-intensive that organic tillage uses less energy in total. The need of grain drying weighs a lot in Finnish alternatives. The energy need of grain transportation is quite small.

For the reliability of the results we can change some of the presumptions. According to calculations these results are not sensitive to changes of variables. In a good year, Finnish rye is more competitive with German rye than the results show, but because of variability of climate conditions the long-time average yield is quite low in Finland. In Germany yield is quite steady year after year. The fertilization rate could change yields in Finland but it also depends on weather conditions. In a suitable year there is no or little need for grain drying, but this is quite unusual. Changes of transportation distances within production country affect energy consumption by only a few per cent in each scenario.

In all, these changes may reduce differences of energy consumption between alternatives, but in the long run the sequence of compared scenarios does not change with technology and cultivation methods of rye today.

The results show that organic farming uses less energy than conventional tillage on rye production. Another important and surprisingly clear point is that transportation of grain uses quite little energy compared to, for example, grain drying. That is the reason why Finnish rye production cannot compete with the Central-European rye production in energy efficiency, assuming that they have the same production method.

Most of the energy in conventional rye tillage is used for fertilizer manufacturing. This is caused by a high-energy demand of nitrogen production. Therefore, also the production methods of conventional farming could be improved for example by using different natural nitrogen fertilization methods.

Because of its geography, Finnish agriculture has an unfavourable situation when compared with more southern areas. The energy needs of grain drying are high and it cannot be compensated in any way given the production method is same as in Germany. If energy for grain dryers could be produced by renewable energy sources, its weight on energy consumption calculations could be smaller because of decreasing environmental effects. This is a great challenge for organic and conventional farming in Finland in the future.

For the Finnish agriculture, the results of the study give support to change a large part of the rye production to an organic tillage system. Probably there is no possibility of effectively decreasing energy consumption of conventional rye tillage the actual technology and cultivation methods. The main problem is a low yield per hectare which causes energy consumption per one kg produced rye relatively high. The cultivation methods themselves are already at least as energy efficient per cultivated hectare as in Germany.

From the point of view of energy consumption it would be reasonable to produce only organic rye in Finland. Because of lower yields the need of rye import would then be higher than now. Economically, however, it is impossible because of the structure of the actual support system, and also the quality of rye could be a problem at time. But in the future negative effects of energy use will be more actual while on the other hand, the price of will probably energy be higher than now. Then there can be some difficulties to finding reasons for rye tillage in Finland with high need of expensive and imported energy inputs. Now it would be very important to give some attention to energy use of agriculture and get a leading position for energy efficient methods and technology. That would be one reason to keep the agriculture alive in the north because it has also many positive effects to landscape, regional economies, ecosystems and peoples of rural areas. Money may not be the only argument when we decide what is the future of agriculture in Finland.

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Environmental aspects of a local food supply system – report from an ongoing project in Järna

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Background

The work presented here is a part of a larger ongoing project in Järna called "Local consumer and producer co-operation for high food quality, good resource conservation and better environment". The project aims at creating a locally based food supply system in the Järna region by initiating and stimulating co-operation between organic farmers, local processors, distributors, and consumers. That is, the project is action research oriented in the way that the researchers take an active part in the process (actively and purposefully affects the "object" of study) and, at the same time, study the system and its development. So far, three subprojects have been initiated: 1) Effects on the environment and natural resources consumption, 2) Economic consequences: Economic new orientation of the primary production through local ecological production, and 3) Documentation of the process – driving forces, motives, and obstacles for consumers and other actors. It is the first of these three subprojects that will be presented in this paper.

Aim and scope

The aim (of subproject 1) is to develop knowledge that can be used as decision support for local actors (producers, processors, distributors, and consumers) in the development of a locally based food chain in the Järna area. Through documentation and calculation of possible environmental gains and lowered consumption of natural resources that can be achieved compared to conventional food supply systems, the actors (and researchers) are given knowledge of the environmental impacts of different development strategies. The aim is to give every actor in the system knowledge and understanding both of his/her own environmental performance, as well as of the whole system's performance. This will be done by comparison of ecological with conventional agriculture, as well as local small-scale with conventional large-scale ("Swedish average") food processing and distribution. The aim is also, since this is a pilot project, to develop and try out methods for the researchers to work in close collaboration with the local actors – methods that can be used also in other places in the essential development of the society in a sustainable direction.

Method

The environmental impacts and use of natural resources will be calculated for each part of the food chain in Järna (from primary production to consumption), using computerised systems analysis models. Life cycle assessment methodology (LCA) is used for impact assessment, i.e. the recalculation from emissions of gases and substances to environmental impacts. We have chosen to include four of the impact categories (or parts of them) given by Lindfors et al. (1995). The four are: 1. Resources – Energy and materials (consumption of primary energy resources and plant nutrients), 2. Eutrophication (emissions to water of nitrogen compounds and phosphorus), 3. Global warming (emission of carbon dioxide, methane, and laughing gas), and 4. Acidification (emission of ammonia, nitrogen oxides, and sulphuric oxides). More impact categories like e.g. Habitat alterations and Biological diversity can be included at a later stage.

Computerised models are used with the objective that they and their results will be useful decision support tools for the actors who want to develop the food supply system in the Järna region. The graphical interface, created in the modelling programme Matlab/Simulink (The MATHWORKS Inc., 1997), makes it possible to give the involved local actors a picture of the system – how different parts are connected, how the parts influence each other, and which importance the parts have for the whole system. The uppermost layer of the model, as it is represented on the screen, is shown in figure 1. Each "box" is a submodel that in turn consists of submodels in one or several underlying layers.
Since results are presented for each part of the system, as well as for the whole system, it is easy to identify the parts that have large impact and the parts that have a lower impact, thus being of minor interest – a socalled hot-spots analysis. The models also make it possible to simulate different system designs in order to assess their environmental performance, without the construction of the real system. The concept was first developed for simulation of organic waste management in a project called ORWARE, see e.g. Nybrant et al. (1996) and Sonesson (1999), and later in analyses of small-scale organic waste systems and small-scale food-supply systems (Thomsson, 1999).

So far, initial studies of the primary production (agriculture) have been performed and the assessment of the processing step has started. The assessment will then continue with the horticultural production, distribution, and consumption parts of the food chain. When today's system – both the parts and the whole – is surveyed, deeper studies of different future scenarios will be performed in collaboration with the local actors in the food chain. By this, both the research and the development of knowledge among those who want to develop the local food supply system in the Järna region will be promoted.

The data are collected through inquiries, interviews and, where needed, access to the companies' bookkeeping. On the farms, the detailed farm data and plant nutrient balances that have been documented in several years. Data from the deep studies of the Skilleby farm (Granstedt, 2000) are also used. Among the consumers, repeated inquiries and interviews are performed to get quantitative basic data for calculations both of how much food of different kinds is consumed, and of how large apart of these foodstuffs is of local origin. Data for consumption and emissions for fuels, electric generation, machinery work, transports, supplies to processing and primary production, etc. are collected from literature, e.g. Cederberg, 1998; Davis & Haglund, 1999, Geier et al., 1998; Habersatter et al., 1998; Hansson et al., 1998; Lindfors et al., 1995 and Uhlin, 1997.

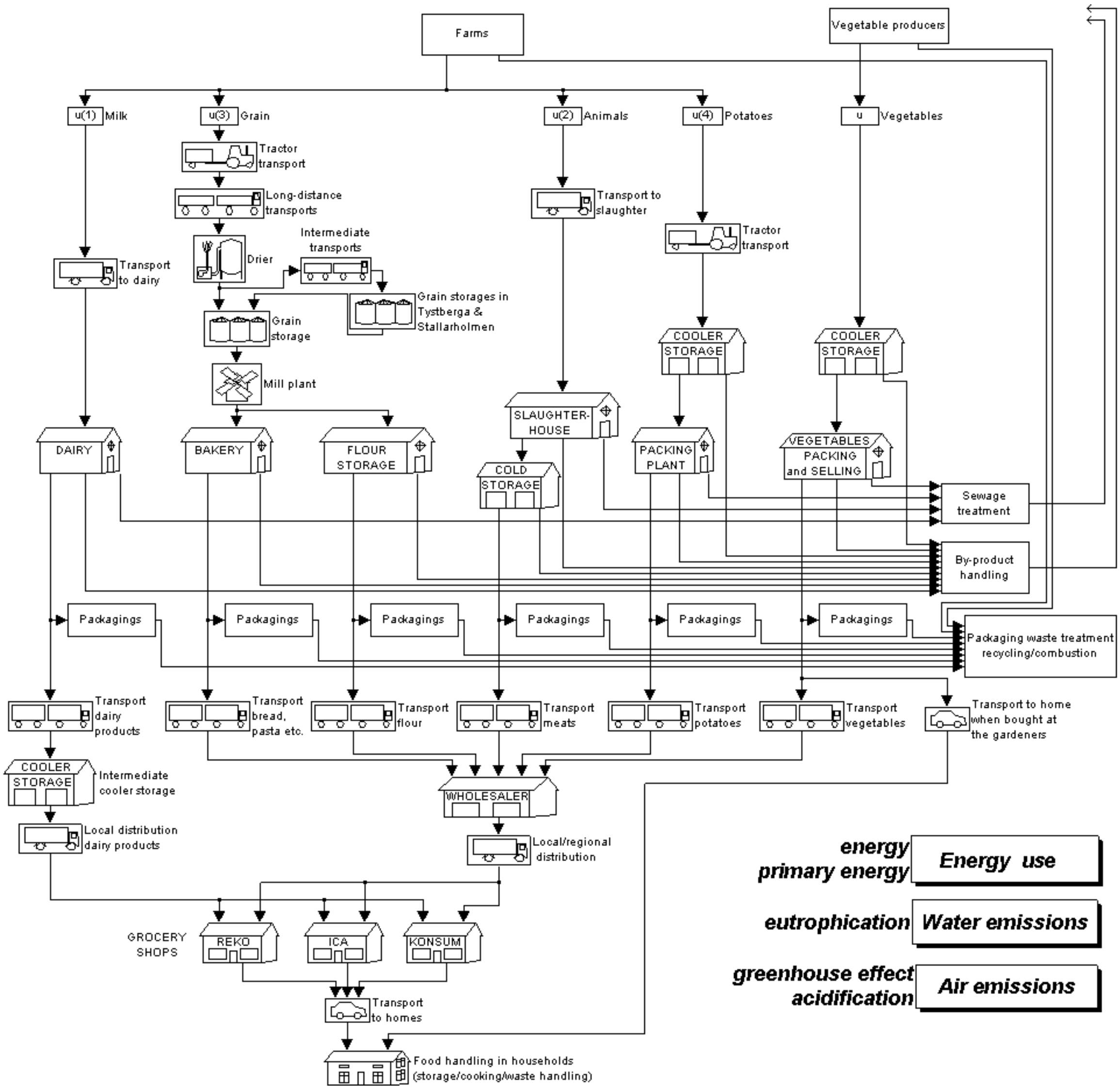


Figure 1 **The uppermost layer of the model as it is represented on the screen in Matlab/Simulink. Each "box" is a submodel that in turn consists of submodels in one or several underlying layers**

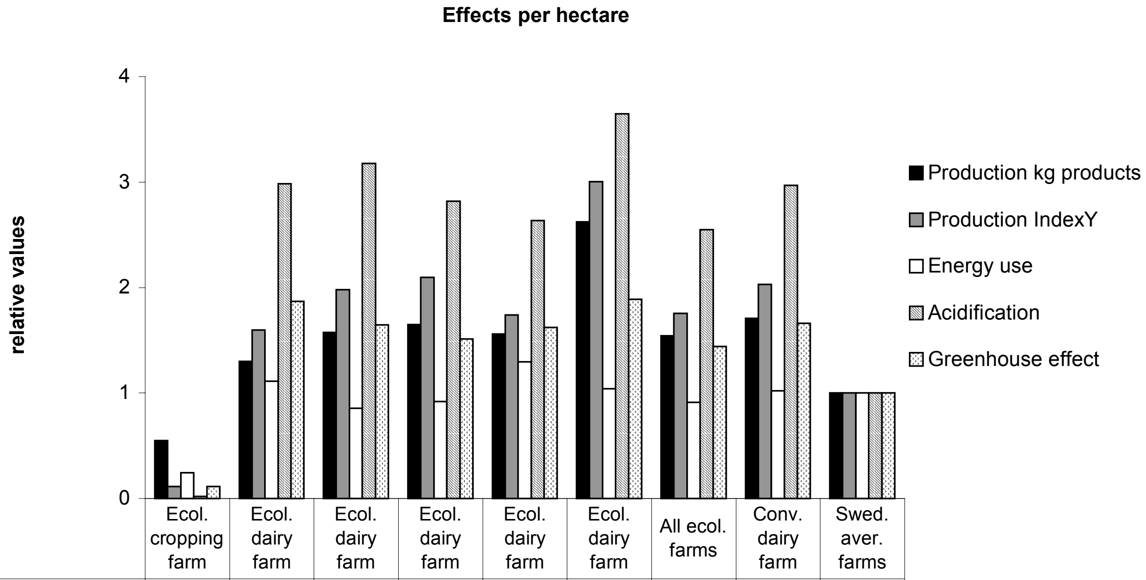
Agriculture – some preliminary results

Some *preliminary results* for the agricultural farms are presented here. Since they are not complete, they should be considered as provisional and not be treated as conclusive results.

Six organic (biodynamical) farms and one conventional one are, so far, included in the study. There is one organic farm with mainly arable crops and some animals held for meat production, five ecological diary farms and one conventional dairy farm. For comparison, also the average for Swedish agriculture (all production types) is included. Further, in some of the analyses, the six ecological farms have been aggregated to show the performance of the farms as an entity. The reason for this is that the consumers, buying locally produced food, often look upon the farms as one actor on the market and, thus, have an interest in the aggregated results. However, one should remember that the aggregated results are difficult to compare to the other results, since there are large variations between the farms and since the ratio between arable/dairy farms in the aggregated eco-farms is not the same as the ratio between arable/dairy farms in Swedish agriculture.

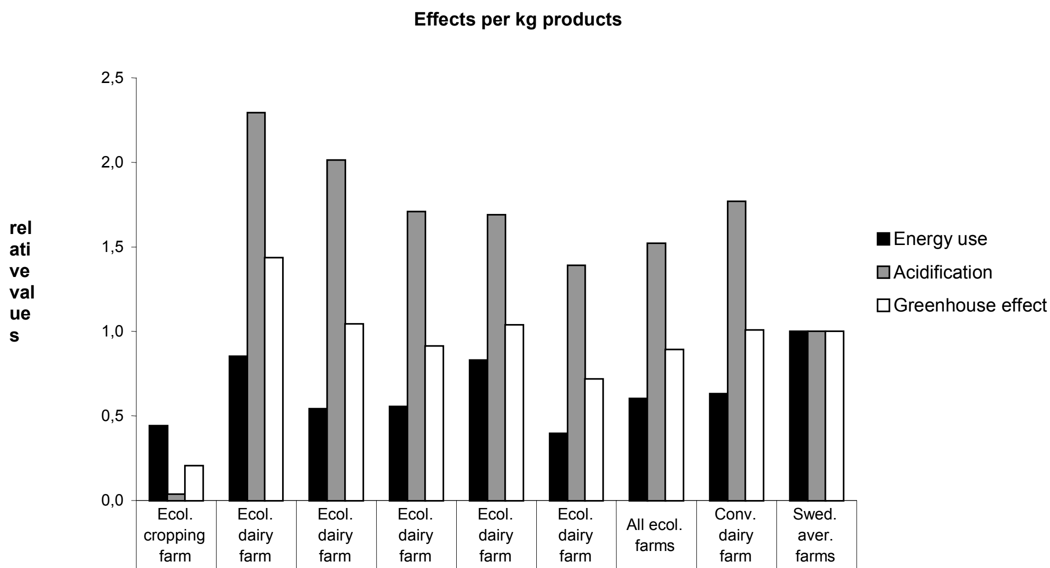
The production and environmental impacts per hectare arable land are presented in figure 2. As can be seen, the dairy farms seem to have a large part of the acidification impact – mainly due to ammonia emissions from the stables. However, the outdoor animals on the mainly arable farm have not yet been incorporated in the calculation, as they will be in a later stage. Furthermore, the dairy farms have a larger production due to a more intense utilisation of the acreage. When the environmental impacts are compared on a per kg production basis (figure 3), the difference in amount of food produced is partly compensated. In an attempt to further compensate for the fact that animals produce a smaller amount of kg products with a higher quality, the IndexY was tested as a measure for evaluation (figure 4). Index Y is an energy correction of animal production following a concept presented by Jan Jansén (2000). The correction is done by multiplication of every kg of animal product by 10. It is based on the fact that in most ecological systems, every higher step in the hierarchy (ecological web) comprises only a tenth of the energy, compared to the level beneath it, but has a higher "energy quality". This is a rather rough measure and it will, if at all used, be developed.

Yet another comparison that can be made is the impacts per number of animal-units (not shown). Other measures might be developed when a closer collaboration with the farmers starts. More detailed analyses will also be performed. An example of a detailed analysis of the energy use is shown in figure 5.



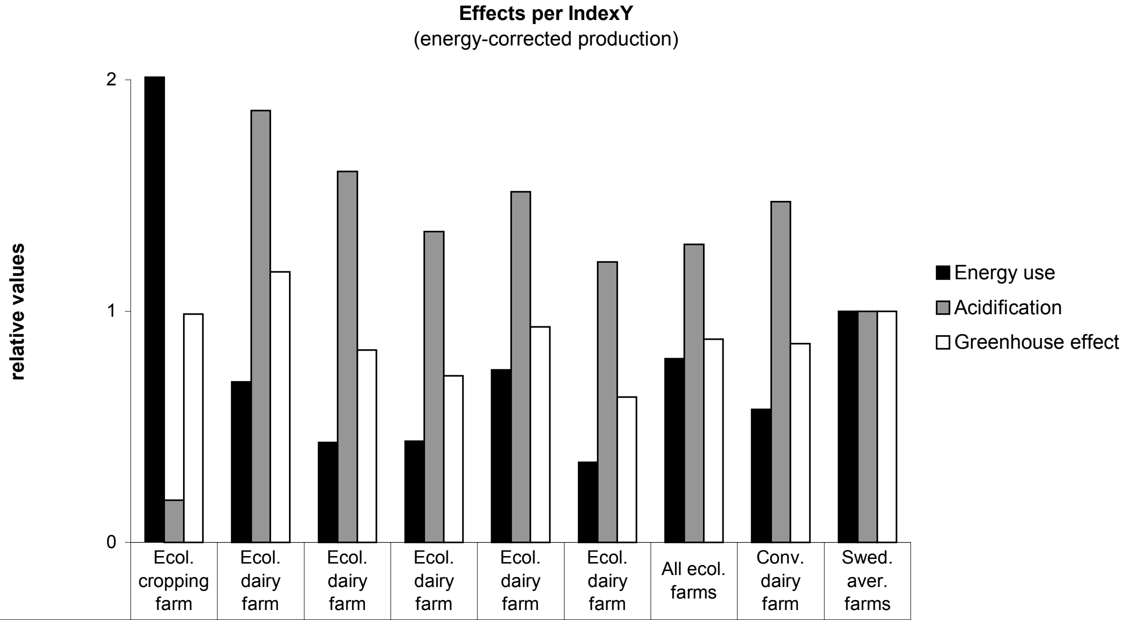
	Ecol. cropping farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	All ecol. farms	Conv. dairy farm	Swed. aver. farms
Production kg products	0,5	1,3	1,6	1,6	1,6	2,6	1,5	1,7	1,0
Production IndexY	0,1	1,6	2,0	2,1	1,7	3,0	1,8	2,0	1,0
Energy use	0,2	1,1	0,9	0,9	1,3	1,0	0,9	1,0	1,0
Acidification	0,0	3,0	3,2	2,8	2,6	3,6	2,5	3,0	1,0
Greenhouse effect	0,1	1,9	1,6	1,5	1,6	1,9	1,4	1,7	1,0

Figure 2 **Production, energy-corrected production, energy use, potential acidification and potential greenhouse effect per hectare arable land on the seven different farms, the six ecological farms aggregated (in "All ecol. farms"), and Swedish average agriculture *(relative values; Sweden=1)***



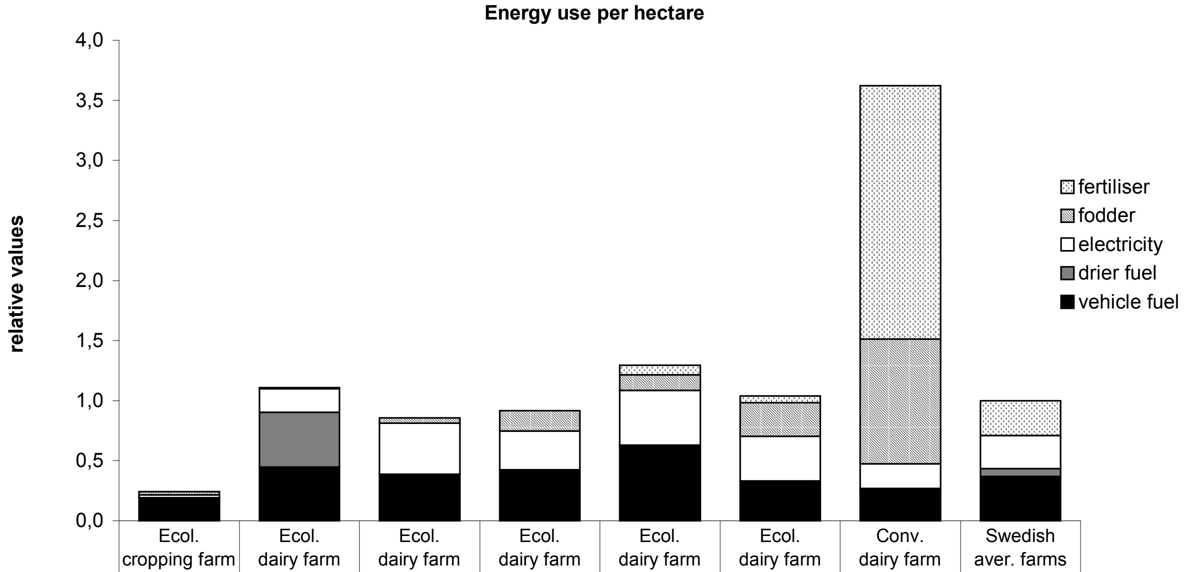
	Ecol. cropping farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	All ecol. farms	Conv. dairy farm	Swed. aver. farms
Energy use	0,4	0,9	0,5	0,6	0,8	0,4	0,6	0,6	1,0
Acidification	0,0	2,3	2,0	1,7	1,7	1,4	1,5	1,8	1,0
Greenhouse effect	0,2	1,4	1,0	0,9	1,0	0,7	0,9	1,0	1,0

Figure 3 **Energy use, potential acidification and potential greenhouse effect per kg products produced on the seven different farms, the six ecological farms aggregated (in "All ecol. farms"), and Swedish average agriculture (relative values; Sweden=1)**



	Ecol. cropping farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	All ecol. farms	Conv. dairy farm	Swed. aver. farms
Energy use	2,1	0,7	0,4	0,4	0,7	0,3	0,8	0,6	1,0
Acidification	0,2	1,9	1,6	1,3	1,5	1,2	1,3	1,5	1,0
Greenhouse effect	1,0	1,2	0,8	0,7	0,9	0,6	0,9	0,9	1,0

Figure 4 Energy use, potential acidification and potential greenhouse effect per kg energy-corrected products (IndexY) produced on the seven different farms, the six ecological farms aggregated (in "All ecol. farms"), and Swedish average agriculture. (relative values; Sweden=1)



	Ecol. cropping farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Ecol. dairy farm	Conv. dairy farm	Swedish aver. farms
fertiliser	0,00	0,00	0,00	0,00	0,08	0,06	2,11	0,29
fodder	0,03	0,01	0,04	0,17	0,13	0,28	1,04	0,00
electricity	0,02	0,20	0,43	0,32	0,45	0,37	0,21	0,27
drier fuel	0,00	0,46	0,00	0,00	0,00	0,00	0,00	0,07
vehicle fuel	0,19	0,45	0,39	0,43	0,63	0,33	0,27	0,37

Figure 5 Energy use per hectare (relative values; Sweden=1). The relative value 1 corresponds to about 10 000 MJ/ha. Note that fodder is not included in the value for the Swedish average agriculture (Sweden)

Discussion

The results presented, though preliminary and not complete, give rise to some questions about how to compare environmental impacts from different production systems and scales. For example, the acidification impact from dairy farms is much larger than that from the farms with mainly arable crops. The conclusion could then be that we should be vegetarians. But, on the other hand, then we should also have to stop drinking milk, since most of the acidificating emissions in the studied system come from dairy cows. However, if other environmental impacts as open landscape and biodiversity are taken into account the conclusion would probably not be that we should be strict vegetarians. In that case, a more reasonable conclusion would be that a diminished consumption of animal products and – maybe more important – a change from consumption of grain-fed animals kept indoors (e.g. pigs and poultry) to grazing animals (e.g. cattle and sheep) would be beneficial for the environment in Järna. On the other hand, more grazing animals might result in more global warming and/or acidification impact (not studied yet) implying that results for different environmental impacts might point in opposite directions.

Our belief is that we can never give a scientifically based straight answer to these questions since there are too many different aspects to consider and too much of personal values and preferences mixed into the problem. What we can do is to analyse and compare different food supply systems or system settings. Starting in 1) different food demands (diets) of the inhabitants in the studied area and 2) different ways of producing these demands, we can compare a number of alternative scenarios. In the project we will start with the local "ecological" consumer's environmental impact and compare it to the average consumer's impact. When this is performed we will continue with comparisons of changed consumption patterns and different production and distribution scales.

In any case, one must bear in mind that the kind of analysis performed in this study is not enough – other methods have to be used for the inclusion of e.g. qualitative data in the assessment. But, hopefully, the results, and the questions they create, can work as one of several means to promote open-hearted dialogue and co-operative learning amongst the actors in the search for knowledge about, and development of, a sustainable food supply system in Järna as a good example for other similar initiatives for the future society.

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Spelt - a pilot crop to strengthen co-operation between farmers, food processors, distributors and consumers

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Introduction

In 1993 a farmer and baker producing biodynamic food asked me about a source of supply for spelt seeds in Finland. This question waked my interest in spelt cultivation because I found out that spelt seed is not dealt in Finland although already some cultivation experiments were done at the University of Helsinki as well as in Turku and Vihti, among other places. So I ordered some seed from Germany and 1994we tried in cultivation of spelt on his farm, in my garden at Helsinki, and on the research farm of the Agricultural Engineering Research unit.

The Finnish biodynamic journal "Demeter" published the outcome of our trials in 1996 followed by the journal of Finnish organic farming union, in those days named "Omavarainen maatalous" (= self-contained agriculture). As a result, in 1998, some farmers founded the Finnish spelt association following a spelt seminar held at Agrifood Research in Jokioinen to promote cultivation, processing, and consumption of spelt. Meanwhile, I estimate the cultivated area of spelt in Finland to be about 200 ha.

The following observations and conclusions about processing and marketing spelt products in urban areas are based on my experiences as chairman of the Finnish spelt association during the year 2000, in co-operation with the farmer couple, Sirkka and Kalervo Rekola, at Raikku near the city of Tampere, and in co-operation with Kari Kaipainen, chairman of organic farmers association Vihti. Kalervo Rekola started spelt cultivation in 1995 and his wife is baking and selling bread from biodynamic cereals cultivated on their farm. Mr. Kaipainen started marketing the spelt yield of our research farm this year.

Special properties of spelt

Spelt (Triticum spelta L.) is ancient wheat, widely grown in Central Europe until the end of the 19th century. Lower yield compared to wheat, brittle spikes consisting of spikelets containing 2-3 grains, and high proportion of difficult removable husk is compensated by high protein content, high straw yield, and the ability to reach acceptable yield under unfavourable conditions. Hildegard von Bingen mentioned spelt in her medical textbook written in the 12th century because of its healthy nutritional properties and it is said that wheatallergic persons tolerate spelt products.

Motives to cultivate spelt and to market spelt products

There are three reasons why spelt was interesting for Finnish farmers and researchers: Curiosity about crops and local breeds suitable for organic farming, economic benefits and competition leadership by marketing new niche products, and consumers' demand for healthy and high quality food produced pro-environmentally. Figure 1 shows how the special properties of spelt and the reasons for cultivating spelt offer starting points for co-operation. Chapter 2 follows the structure of this figure.

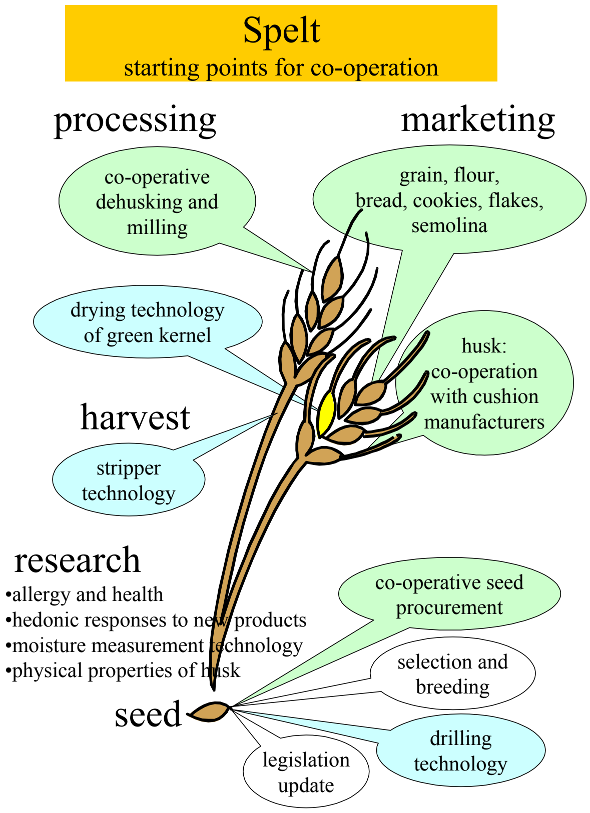

Figure 1 Spelt - starting points for co-operation

Starting points for co-operation

Seed

Procurement

The first barrier cultivating spelt is the difficulty of seed procurement. At the beginning of spelt cultivation, seeds were imported from German, Swiss, and Belgium seed companies. Later on, when certified organic seed was asked for, a Finnish wholesaler of organic products in Helsinki, Itu Ltd., co-ordinated collective orders of seed. Importing small quantities of seed resulted in high seed cost where transport share was more than 50%. Two farmers near the city of Kauhajoki established in 1997 an enterprise, Merinomi Ltd., which imports organic certified spelt seed in quantity lowering transport share cost to 30%.

Propagation of spelt seed

Efforts of the Finnish spelt association to lower seed cost by propagation of certified spelt seed in Finland revealed that propagation is presently not legally possible because the official seed variety list of state authorities does not include any spelt variety. It seems that the national legislation has not been yet adapted to EU-legislation.

Selection and breeding

MTT Agrifood Research Finland started first preliminary cultivation trials comparing different varieties of spelt in 1995 at the research station in Peipohja and continued since 1996 at the research station in Ylistaro. The aim is to find the varieties of spelt best suited for Finnish conditions. Selection and breeding of suitable varieties adapted to Finnish conditions will be a task for the future.

Drilling technology

Drilling spelt spikelets is difficult because of their size. Especially when row distance is increased, modern drills easily get stuck. According to farmers' reports, old-fashioned cam gear drilling machines show the best results. Distribution of grains is unequal because spikelets may contain one to three grains. The ISO-standard 7256/2 for drilling machines concerning cross and longitudinal distribution accuracy of grains is not applicable because it is created for single grain drilling not for spikelets drilling. Some researchers avoid drilling problems by dehusking spelt seeds before drilling. However, this may influence germination and disease tolerance.

Harvest

Harvest is usually done by common combine harvesters. The brittle spike breaks easily from stem causing harvesting losses. The use of stripper technology may improve harvest results. In case that the stripper combine harvester turns out to be the best technology in terms of losses and efficiency only harvest done by a contractor is economical.

Processing

Before milling, spelt has to be dehusked. Both husk and grain are marketed. Most farmers co-operate with local millers for dehusking. Most of these mills dehusk spelt using equipment designed for oats. Gathering experiences those mills succeeded in reducing losses but they are still high, up to 50%. Another problem is that millers need an appropriate batch for processing. Because some farmers want to sell their own spelt products, one batch is milled immediately after dehusking. If the whole batch cannot be baked or sold at once, flavour, break, and flakes are ageing and product quality may suffer.

Special dehusking equipment is available from German manufacturers, but the equipment is expensive. Up to now two dehusking devices are working in Finland. The Birkkala farm in Suomusjärvi owns one. The farm processes own spelt to flour, flakes, and crisp.

Merinomi Ltd. owns the other machine. Both offer dehusking services to other farmers. Because of long transport distances and the limited production of spelt, presently, the best solution would be a mobile dehusking machine, mounted on a car trailer ready for transport. The Finnish Spelt Association should tackle this solution since dehusking and cleaning of both grain and husk requires proficiency.

A local speciality in Franconia is Grünkern (= green kernel). This is a product made of yellow ripe spelt (variety Bauländer Spelz) dried with smoke of beech wood. Production of green kernel requires a special drying technology. Up to now there is no green kernel production in Finland, but recently the MTT Agricultural Engineering Research Unit launched a project on technology of disinfecting seeds by smoke. So, the drying technology for green kernel production is available.

Products

Besides Grünkern there are many different products made of spelt: Whole grains, flours, break flour, flakes, semolina, and noodles. Boiled whole grain replaces rice and germ products replace vegetables. Excellent bread and cookies are baked from flour. Husk is used to fill mattresses and cushions or as litter.

Marketing

Many farmers are marketing their own spelt products. E.g., the Birkkala farm sells the products through ten retailers mostly in Turku and Espoo but also in Jyväskylä. Many customers also buy the products by cash on delivery.

Rekola's farm established its own bakery with a turnover of about 10 tons of biodynamic cereal products per year, 10% of which were spelt products. Besides bread, also muesli, flakes, and break flour products are manufactured and transported to healthy food retail shops in Tampere and Helsinki. The baking period starts in autumn and ends in spring. The products are signed with the Demeter label and with Rekola's label. Demand is greater than supply and spelt products are mainly asked for diet and health reasons. Co-operation between farm and retail traders is close. In addition, the relationship to customers is very important. A group of about ten customers visits the farm monthly and organises an event once a year. Dehusking is done in co-operation with an interested miller at a local mill that processes 800 kg batch. Good quality husk is sold to cushion manufacturers and the rest is used as litter for cowshed. Rekola observed that cows also like to eat the husk.

In 2000, spelt produced at the MTT Agricultural Engineering Research Unit was sold to a local mill at Mustio near Helsinki, which processes only organic products. Spelt products of this mill are marketed by the miller himself and by a wholesale company for organic products in Helsinki. In 2001, the chairman of the local organic farmers' association at Vihti, Kari Kaipainen, contacted the MTT Agricultural Engineering Research Unit for buying spelt. He is a salesperson by profession and convinced that spelt is a healthy product, environment-friendly produced. His vision is that agricultural products should be marketed locally to make consumers independent of marketing strategies and nutrition philosophy of main stream agrifood industry. Further, he wants to promote small-scale industry at the countryside. To support his vision, he applied for project funds at the Employment and Economic Development Centre for Uusimaa. The project aim is to co-ordinate processing of spelt and to analyse markets for spelt products.

He is co-operating with a miller at Iittala who is dehusking the spelt and milling semolina, flour, flakes, and break flour. The mill does not limit the batch size. This year he sold about 2500 kg of spelt products. He presently counts about 300 customers in the area of Uusimaa. They are relatives, friends, neighbours, kitchen personnel of day-care centres, schools, and restaurants. About 30% of his customers already knew about spelt.

The Finnish spelt association aims to promote spelt cultivation and marketing. The association organised two seminars in co-operation with the vocational training school for Agriculture of the City of Kauhajoki. The school had started a project to develop spelt cultivation on the initiative of two spelt farmers. The project was funded by the EU 5b Leader programme. Additionally the project offered space on a website for the Finnish spelt association (www.spelt.net). Members of the association attended numerous exhibitions to inform the public about spelt cultivation and spelt products and to recruit new members. The Agricultural Engineering Research Unit of MTT Agrifood Research Finland also attended several exhibitions and trade fairs, figure 2.

Research

Dealing with spelt raises many questions still waiting for an answer concerning properties and cultivation of spelt as well as the impact of spelt on nutrition and health. It is said that wheat-allergic persons may eat spelt products of old and genuine spelt varieties. The term wheat allergy is scientifically unclear. However, what does "old" and "genuine" mean in terms of physiological or chemical properties? Celiac disease is caused by gluten, a protein that is also part of spelt proteins.

Nevertheless, members of the Holy Hildegard Society, which is active in several towns all over Finland, and several other people state that even patients suffering from celiac disease can eat spelt products. However, scientific publications that confirm such a claim could not be found so far.

Another field of research is the development of new products made from spelt. Grünkern products may substitute meat similarly as soybean products because of its flavoursome taste. Co-operation with the Department of Food Technology of the University of Helsinki resulted in a study about consumers' acceptance of products made from Grünkern.

Many open questions concern physical properties of spelt and spelt husk. Answers to these questions are important for a successful cultivation and husk product development. E.g., present grain moisture meters do not indicate the right figures when measuring spelt moisture. The special physical properties of husk that favour them for filling mattresses and cushions are still unknown.

Figure 2 Spelt poster of MTT Agricultural Engineering Research

Conclusion

Introduction of spelt cultivation to Finland showed that this versatile cereal created new initiatives amongst farmers, processors, traders, and consumers, because there were no established infrastructure to process and market locally produced spelt products. The "new" crop also raises questions concerning legislation, research, nutrition, and health. To answer the open questions, financial support is necessary. However, in spite of the lack of public financial support, farmers already successfully contributed to bridge the gap between consumers, traders, and producers. The most important challenge for the future will be to find new ways to learn co-operation. This concerns not only sharing common purchased equipment but also the development of common strategies in the sense of brotherliness in economic life. Spelt offers ideal opportunity to train the required faculty and social capacity of farmers, processors, traders, and consumers.

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Establishing the Economic and Social Infrastructure of a Community-Scale Food System

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Abstract

This paper lends empirical support to the discussion regarding the development of community-scale food systems by highlighting the efforts of a small island community in the USA to develop a local food processing center. The socioeconomic and geographical context of the community is outlined so as to allow inferences to be made regarding the applicability of their efforts to other contexts. The importance of creating an agricultural infrastructure supportive of small-scale and limited-resource producers as the basis upon which to establish a community food system is highlighted, as is the importance of multi-stakeholder involvement in developing the social institutions which accompany community food systems. Drawing on statistical data, the emerging alternative food system literature and the personal experiences of the author, this paper is intended to add to the discussion regarding the establishment of food systems that operate at the scale of local communities.

Keywords:
Food systems; Community-scale; Economic infrastructure; Social infrastructure.

Introduction

Within alternative agriculture movements, food systems have been increasingly identified as entities around which communities can organize in order to achieve a diverse range of ecological, political and socioeconomic goals (Kloppenburg et al., 1996). While the environmental aspects of food production have received attention from consumers and researchers for decades, the concept of sustainable community food systems is a relatively recent phenomenon in the sustainable development and ecological agriculture discourse. In the industrialized world generally, and in the US in particular, there appears to be a trend toward the evolution of two distinct food systems which can be aggregated conceptually as operating at either a global or a community scale. Over the last fifty years, the economic and agricultural infrastructure of the global food system has steadily evolved towards greater economic concentration and vertical integration in food production, processing, distribution and marketing (Lehman & Krebs, 1996). This has resulted in a food system that no longer serves the economic needs of small-scale farmers or the needs of consumers for fresh, locally grown food.

In order to bypass middlemen and directly support small farms, ecologically oriented farmers and community-minded consumers have revitalized such direct marketing structures as farmers' markets and invented new structures such as Community Supported Agriculture (CSAs). Although the direct linking of farmers with consumers is a powerful way to create local alternatives to the global food system, studies have shown that it is the processing and distribution sectors of the food system that divert the greatest share of every dollar spent on food and are the segments of the food system that consume the majority of the resources (Johansson et al., 1996; Pretty, 1998). Therefore, the evolution of complete food systems that are properly scaled to the needs of local communities and small-scale farmers will require the development of appropriately sized food processing facilities and marketing outlets, as well as other new forms of economic and social infrastructure, at the local level. Furthermore, it is the development of this infrastructure that represents the critical barrier to be crossed in order for a complete, well-functioning community-scale food system to be established. This paper lends empirical support to the discussion regarding the development of community-scale food systems and highlights the efforts of a small island community in the USA to develop a food processing center with the intention of strengthening the local agricultural economy and reducing their community's dependence on imported food. Statistical data and information drawn from the author's personal experience are presented to outline the socio-economic and geographic context of the community and to allow inferences to be made as to the applicability of their efforts to other places.

Food System Diversity and Resilience

For the purposes of this paper, food systems are defined as the combined assemblage of growers, processors, distributors and consumers of food, the agricultural land upon which these human actors and organizations depend, and the dynamic relationships between these essential parts. Within a food system, each component performs a more or less specific function, is nested to subsequent components and interacts with a diverse number of social and economic systems at a variety of scales. As food systems fulfil a fundamental biological role for society and because a primary way in which humans interact with the biosphere is through food systems, the use of a ecological metaphor to describe food system diversity and function is pertinent. Peterson and his colleagues (1998) offer an ecological model in which ecological resilience is generated by the species richness and functional diversity present in an ecosystem. Applying this metaphor, we can imagine that diversity within a food system is comparable to species diversity within ecosystems, with each component performing a critical role in the proper functioning of the system as a whole. Food production, processing, distribution and marketing are the main functional roles to be fulfilled by different actors in the food system and as the process of farm consolidation and vertical integration in food processing and distribution sectors has progressed, the functional diversity in the food system has decreased. This process is leaving some essential functions neglected and may lead to an overall diminution of resilience in the system as a whole.

The Global Food System

Modern intensive agricultural systems are the foundation of the global food system. These systems are generally designed for peak economic performance through the efficient production of standardized agri-cultural commodities, often irrespective of the long-term demands of social and ecological sustainability, expressed as rural community and agroecosystem health (Waltner-Toews & Wall, 1997). While modern intensive agriculture has successfully increased production in-step with an expanding human population (Kendall & Pimentel, 1994), it has done so at great cost, and both individual farms and entire agroecological regions that are coupled to the global food system are experiencing negative side-effects as a result of this coupling. From the perspective of rural community health, the situation is disheartening in many parts of the world. Many rural communities are suffering from socioeconomic and population decline and many farmers have been forced to intensify production and/or diversify their livelihood strategies in order to stay in farming (Djurfeldt & Waldenström, 1999; Pretty, 1998).

Viewed through the lens of ecosystem services, which are these services, freely provided to humans by nature, and upon which rests the economic and social well-being of society (Daily, 1997), the global food system is implicated on a number of fronts. Röling (1997) has stated that the sustainability of land use is largely a matter of maintaining and enhancing the ability of agricultural and resource lands to provide vital ecosystem services. Studies have shown that the intensification of production, which is often required for farms to remain economically feasible in the global food system (Djurfeldt & Waldenström, 1999) has led to a diminished ability of agroecosystems to generate essential ecosystem services (Björklund et al., 1999). The scale at which the global food system operates is considered by some to be at the core of the problem. Therefore, it is through developing food systems that operate at scales more appropriate to local communities that many see a possible remedy to the dysfunction that plagues the global food system.

Community-Scale Food Systems

Community-scale systems of food production, processing, distribution and marketing have emerged as farmers and consumers have organized to meet food needs in a way that is appropriately scaled to the agroecological and economic circumstances of their local communities (Kloppenburg et al., 2000; Feenstra, 1997). I define community-scale food systems as place-based food systems that are designed to serve the consumers and farmers that live in a common socio-geographic space. I use the term community-scale as opposed to community-based food systems because I think it is important to highlight the role that scale plays in the structure of food systems and the effect that this has on both farms and consumers linked by a food system. Community-scale food systems are often arranged to support small-scale and organic farmers, and in this way, organizing for community-scale food systems is both an expression of an expanding ecological consciousness and a movement toward community controlled economic development (Campbell, 1997). A common conception of community-scale food systems is that they have the potential to foster an increase in social capital within rural communities and between rural and urban communities through direct and more frequent farmer-to-consumer and farmer-to-farmer contact (Pretty, 2001). However, in her study of farmer's markets and CSAs, Hinrichs (2000) emphasizes that power and privilege play a role in any market interaction regardless of setting.

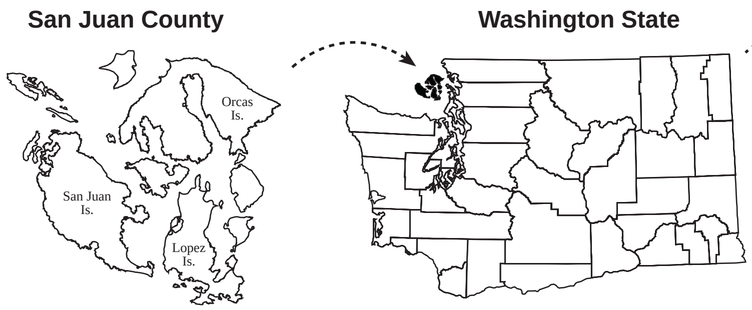
While the growth in the demand for organic food products has directed a substantial amount of financial resources towards producers that are employing more sustainable practices of land stewardship and animal husbandry, much of the infrastructure that processes and delivers produce from organic farms to consumers has remained unchanged. Researchers at the Swedish University of Agricultural Sciences have estimated that refinement, processing, distribution and marketing account for 65% of total resource use in the Swedish food system (Johansson et al., 1996), while the production and preparation of food account for the remainder. A study by Wilkinson (1997) in the USA, which focused on the economics of sustainable community food systems, indicated that farmers received 4-10% of each food dollar spent by consumers while processors, distributors and marketers received the rest. In the movement to develop sustainable community food systems, the intermediate sectors of the food system are often neglected and represent a clear focal point around which to organize for change.

San Juan County Food Processing Center

The San Juan County Food Processing Center (SJC FPC) in Washington State, USA is an example of a grass-roots initiative to develop community owned and controlled infrastructure for small-scale food processing. The SJC FPC has evolved under the umbrella of an organization called the Lopez Community Land Trust (LCLT) and has recently spawned the formation of the Island Grown Farmers Cooperative (IGFC). The LCLT and ICFC are located on a small rural island in the San Juan archipelago, close to the Canadian border (see Figure 1). The San Juan County Food Processing Center (SJC FPC) is a project of the LCLT's Sustainable Agriculture and Rural Development program and was born from the desire to reconnect local farmers and consumers, which had been alienated from each other due largely to regulatory and economic barriers. The following is the vision statement of the SJC FPC:

> *The purpose of the San Juan County Food Processing Center (SJC FPC) is to strengthen and add to permanent agriculture infrastructure in San Juan County. The center will be a facility for businesses and individuals to process meat and plant products for value–added markets in San Juan County and the Puget Sound region. The goal of the San Juan County Food Processing Center is to make San Juan County less dependent on imported food products by providing facilities, services, and education that support a stronger community–based food system. The FPC will provide processing facilities for agricultural products grown in San Juan County for small–scale family and commercial processing. Small and limited resource producers are the highest priority groups served by the center, though the center will be open to all. It will be a gathering place to try diverse approaches and discuss ideas for building a vital local food economy.*
>
> (www.lopezclt.org/sard/sjc_fpc.html)

Figure 1 Locator Map of San Juan County, USA



The SJC FPC is intended to support island agriculture further by providing access to food storage equipment, assistance with harvesting, marketing and distribution and the promotion of cooperative education services. The operating principles adopted by the SJC FPC Project Development Committee are as follows (from LCLT, 2000):

a) Achieve broad support through cooperative development including producers, consumers and marketers.
b) Phase in capacity to produce/ process a broad variety of local products based on market demand, production capacity and business feasibility.
c) Supply local food products to local markets first, then to other markets.
d) Offer educational and processing services to limited-resource farmers and families (non-commercial).
e) Provide for non-profit community ownership of capital assets of the FPC to ensure long-term financial viability and ongoing public service.
f) Incorporate locally applicable best practice standards adopted by island farmers for the sustainability of biological resources.
g) Create a management and ownership structure that allows producers to build equity.

These operating principles of the SJC FPC are part of what makes it unique in the region and in the United States. The operating principles indicate a firm commitment to the general betterment of the economic and social conditions that can be affected by the development of the FPC facility. In order to understand why this project has developed where and when it has, an examination of the current economic context, the agricultural resource base, and agricultural activity in San Juan is offered in the next section.

Agriculture in San Juan County

San Juan County has the smallest area of any county in Washington State with just 38,591 hectares of total land area, while the average county in the state has 473,523 hectares (see table 1). The population is also quite small with only 14,000 people, while the average county has 151,131. The islands are exceptionally scenic and their relatively remote location has made them very attractive for tourists, vacationers and second-home owners from nearby metropolitan areas. The attractiveness of the islands as a place to visit and settle is reflected by the fact that between 1970 and 1999, the population of the county grew by 229% (WSESD, 1999), which was the biggest growth rate in the state. This tremendous population growth has resulted in considerable development pressure that has driven up the price of land for all activities, including agriculture. Currently, the average value of farmland with buildings is 13,884 USD/ha (USDA, 1997a). When this figure is contrasted with the statewide average value of land and buildings of 2,944 USD/ha (USDA, 1997b) it is clear that farmland in San Juan County is exceedingly expensive.

Livestock farming in San Juan County is by far the most common type of agriculture practiced, but this was not always the case. Before the 1840s the Lummi tribe of Native Americans lived in the San Juans in semi-permanent villages and subsisted on the area's plentiful salmon, shellfish, deer, elk, waterfowl, roots and berries (WSESD, 1999). The first European settlers arrived in the 1840s and introduced sheep, goats and cattle, planted orchards and began farming vegetables and grain. Until the 1930s when dams brought irrigated agriculture to the eastern part of Washington State, which outcompeted agriculture on the islands, San Juan County was considered the "fruit basket" of western Washington, with the main farm products being apples, pears, prunes, as well as wheat, hops, potatoes, turnips and peas. After the vegetable and fruit processing industries had subsided on the islands, animal husbandry and grain farming took over as the main agricultural activity and it has remained this way since (LCLT Food Processing Center Committee, 1999). Organic agriculture is practiced by many farmers on the islands and those involved in the SJC FPC are particularly inclined to farming using organic methods.

Table 1 Population, land area, and farm statistics for San Juan County and the county average for Washington State

	San Juan County	County Average for Washington State
Population	14,000	151,131
Land area (ha)	38,591	473,523
Land in farms (ha)	6,834	157,512
Percentage of total area in farms	17.7%	33.3%
Number of farms	174	744
Average farm size (ha)	39.3	211.7
Market value of farmland (USD/ha)	$13,384	$2,944

(Sources: United States Department of Agriculture, 1997a, b, c.)

Lopez Island (see figure 1) is the island in San Juan County that is most agricultural in character and has most working farms. In the initial planning stages of the SJC FPC, the facility was to be called the Lopez Community Food Processing Center. While the farms on Lopez Island represent the majority of the land base that the SJC FPC will serve, and the physical infrastructure will be located on Lopez, the facility and associated farmers cooperative has expanded to include all the islands in San Juan County.

Small-Scale Agricultural Infrastructure

Physical and Economic Infrastructure

Two components will combine to form the physical infrastructure of the SJC FPC. The first is a mobile slaughter unit; based on a truck and trailer combination design that will perform United States Department of Agriculture (USDA) inspected "in-field" slaughtering at individual farms. The second portion is the food processing facility that will offer USDA inspected cut and wrap facilities. The most important characteristics that distinguish the operating scale of the SJC FPC are the size of the Food Processing Center's physical structure (approximately 288m²) and the amount of animals and other produce it is designed to process. The fact that the mobile slaughtering unit will allow the economical and ethical slaughter of a limited number of animals per day, and will do so in-field, is also of critical importance. The two components are designed so that they will support the many small farmers who form the foundation of the SJC FPC, who raise their animals to organic standards and strictly on grass pasture. In the development and operating plan of the SJC FPC (2000), it is stated that at the financial breakeven point of 29% capacity utilization, the mobile slaughter unit and the cut and wrap facility are designed to process 160 beef cattle, 1,000 lambs, and 45 hogs per year. At 75% capacity utilization the combined facilities will process 450 beef cattle, 2,200 lambs and 117 hogs. The number of animals processed in an average industrial-scale slaughter-house and meat packing plant in the USA is48,280 beef cattle, 6,114 sheep and lamb and 133,751 hogs (USDA, 2001). Clearly, the comparison of these figures is a vivid indicator of scale.

In terms of meeting San Juan County meat consumption with the predicted output of the SJC FPC facilities, it is clear that, especially in the summer, the facility will not be able to meet total local meat product demands. Rather, the facilities are designed to match the agricultural patterns that currently exist in the islands and to make sure that what is grown locally can be consumed locally. Using average red meat consumption data from the United State Department of Agriculture for the average American of approximately 50.5 kg per person per year (USDA, 2001), we can see that if the SJC FPC were to operate at 75% capacity producing 171,659 kg of red meat products per year (LCLT, 2000), it would be able to meet the yearly red meat consumption of approximately 3,400 people. Given that the county has 14,000 year-round residents, this means that the SJC FPC facility holds the potential to make San Juan County approximately 25% self-sufficient with regard to meat consumption. Because very little of the meat that is grown on the islands can be consumed there currently, this is a significant development towards food self-sufficiency.

Because the capital assets of the SJC FPC will have permanent non-profit community ownership and will employ a collaborative management framework with both community members and farmers involved, its establishment represents a significant addition to the economic infrastructure for agriculture in San Juan County and the region as a whole. In the US, all small cuts of meat to be sold in retail outlets need to be certified by the USDA. Otherwise, consumers must custom meat orders from farmers to a minimum order of 1/4 of an animal. This requires customers to invest in expensive refrigeration equipment and this presents enough of a financial barrier to most customers that it prohibits them from purchasing meat direct from farmers. USDA inspected slaughter facilities require expensive certification which entails meeting all the requirements for food safety as laid down in the Hazard Analysis and Critical Control Points (HACCP) plan which the Economic Research Service of the USDA admits will put small-scale operators at a considerable disadvantage (Crutchfield et al., 1997). Only ten USDA inspected slaughterhouses serve all of Washington State. Any San Juan County farmer seeking USDA certification and the increased value it adds has to ship their animals off island by truck to an industrial sized meat packing plant where the animals may be subjected to questionable handling practices. Furthermore, any value added to the livestock is done so off island, and the meat rarely, if ever, makes it back onto the islands. The physical and economic infrastructure created SJC FPC holds the potential to rectify this.

Social Infrastructure

In addition to the physical components of the SJC FPC, one existing and one newly created social institution are cooperatively engaged in pursuing the development of the SJC FPC. The existing institution, The Lopez Community Land Trust (LCLT) is a ten-year-old grass-roots institution that is committed to the social, economic and ecological sustainability of the island community within which it is embedded. The more recently developed institution is the Island Grown Farmers Cooperative (IGFC). This organization is now actively building monetary and human capital as well as organizational capacity with the intention to make the SJC FPC operational. These two institutions, the participating producers and the future customers represent the social infrastructure of the food system, balancing the agroecological portion and qualifying it as a socio-ecologically coupled system (Folke et al., 1998). It must be noted that there is a great deal of talent working to make the SJC FPC a reality. The diverse backgrounds of the people on the LCLT board, as well as the experience of the staff and community volunteers has been the greatest contributor to the success the project has achieved thus far.

Multi-Stakeholder involvement and the Assessment of Sustainability

Representatives from a varied group of stakeholders have been involved in working together to see the project through to completion. In addition to farmers and the LCLT staff, representatives from the USDA, the Washington State Department of Agriculture, Washington State University Cooperative Extension as well as the local grocery store meat buyer and local citizens are involved and are in constant dialogue. The involvement of all the potentially affected stakeholders is by no means accidental. In their Development and Operating Plan, the committee in charge of the SJC FPC indicates that only by having all those who will be affected by the construction and operation of the SJC FPC involved in its design the project will be successful (LCLT, 2000).

As for scientifically assessing the contribution of the facility to increasing the overall sustainability of the islands, the IGFC and the LCLT have no definite plans towards this end. However, the project has attracted many students with interest in this kind of assessment. But until the facilities are in full operation, it will remain a topic for future research.

Barriers and Obstacles

The SJC FPC represents a major evolution in the prospects for communities to control their own food system. A community that processes their own food, and especially meat, is a rarity in the US and much of the industrialized world and there have been barriers and obstacles on the road to develop the SJC FPC, which have been the source of some frustration and delay. The chief obstacles have been regulatory, economic and relating to the broader community. The regulatory hurdles have been encountered largely in meeting the USDA certification requirements. As the Economic Research Service of the USDA points out, the HACCP regulations required for USDA inspected meat processing facilities to be authorized require a tremendous deal of time and resources to decipher (Crutchfield et al., 1997). Bruce Gregory, the president of the board of directors of the IGFC, recommends dedicating funds to hire a project coordinator to handle much of the regulatory barriers that must be surmounted (pers. comm.). Many of the community's non-farmers are less knowledgeable about agriculture and the role it plays in maintaining the county's economic integrity and the scenic qualities of the island landscape. Thus, some members of the community fail to see the need for the facility and others have opposed the facility due to unwarranted concerns about noises, smells etc., which they think the facility might generate. On the topic of public relations Bruce Gregory offers this advice, "educate, educate and when you are sick of it, educate some more. The public is your customer and advocate".

Conclusion

In closing, alternatives to the global food system are emerging that are intended to be rooted more fully in the communities that they serve. The development of small-scale farm infrastructure and social infrastructure supportive of sustainable agriculture is one part of what could be called a rural renaissance, a rebirth of living close to the land with a greater ecological connection to place. Food processing is a key sector around which communities can organize to affect economic and social change in their communities. It is through adding value to basic foodstuffs that communities can make great strides towards securing a safe and sustainable food supply and create a healthier land-based economy that includes more than just food production. The SJC FPC is a project that, by adding food processing to local food production and marketing, holds the potential to create a complete food system that operates at a community-scale. While there have been both successes and setbacks and the main facility is not yet built, given the momentum already built and the diverse cross section of the community that is working on the project, the odds that they will see the project through are good.

Acknowledgements

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Local food supply chain: A case of rural food processing firms and catering business in Finland

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Introduction

The subject of this paper is the integration of food production and processing, distribution, and consumption on local markets in rural areas. We approach this integration from the point of view of an alternative food supply chain, a local food system as an example. Alternative, especially shorter food supply chains represent the new patterns of food governance and rural development (Marsden & Arce, 1995; Marsden, 2000, Marsden et al., 2000). Supporting alternative food systems at the local level is a way to promote the viability of rural areas and sustain the national food strategy. It is evident that large food companies will grow bigger and bigger and become more global. This means that the significance of national food markets is on the decrease. We assume, however, that the more global the food markets are, the more demand there will be for local food. The fact is that regional and local characteristics such as certain raw materials and dishes, taste, as well as food traditions and food culture will always be closely tied to particular regions and provinces creating and maintaining their identity (Askegaard & Madsen, 1998, Nygård & Storstad, 1998). Moreover, consumers nowadays are more interested in environmentally, economically, and socially sustainable food systems. This has resulted, for example, in the success of farmers' markets in many European countries (La Trobe & Acott, 2000).

One of the main objectives of supporting local food supply chains is to transfer more value to the beginning of the food chain in rural areas (Finnish Rural Policy Committee 2000). Based on this, our first starting point in this paper is that locally produced raw materials and food products may be produced value added and that especially farms and small rural firms could take advantage of this. In the current situation the fact is that many farms and rural small-scale food processing firms face difficulties in getting their products into traditional marketing channels at the national level. For instance, access to the retail channel often requires highly differentiated products according to particular product characteristics (Forsman, 1999). Many farms and small-scale processors, however, offer products that are not highly differentiated food specialities but, rather, products whose added value is based largely on the way they are produced, such as a short supply chain, environmentally sound, organically produced, or a special customer-seller relationship. By focusing on local markets and taking better advantage of locality in their product development and marketing initiatives, farms and firms with this kind of offerings could create efficient and long-term contacts with local customers. This promotes the viability of rural areas by keeping more of the value and cashflows of rural small-scale production and processing circulating within the particular area.

The second starting point in our paper is that among the most important potential customer groups for local food suppliers are local catering businesses, especially institutional food service units (e.g. schools, day nurseries). Some pioneers among the institutional food service units have taken the initiative in purchasing raw materials, semi-finished products, or finished products directly from local producers. Commercial restaurants have also shown some interest in food products offered by local actors. For many catering units it would be natural to increase the use of local raw materials and food products since many of them are already used to purchasing certain specific raw materials or additional foodstuffs directly from farms or rural small-scale food processors (Markula, 1999). In addition to local products, some food service units are also interested in providing meals that are based on organic products.

Based on our starting point, the objective of the paper is to examine the possibilities and preconditions of local food systems as an alternative supply chain in rural areas. The focus is on the local food systems between rural food suppliers and catering businesses. The theoretical foundation for the study lies both in the value-based theories and supply chain management. A special focus is on the modelling of the value creation of local food products from a rural firm to a catering business. We have set the following research questions: 1) What kind of values are created as a result of the use of local food and operating in a local food system from the viewpoint of different chain actors? 2) What kind of experiences do chain actors have from a local food system? 3) What benefits, risks, and sacrifices catering businesses relate to the use of local food? 4) What are the reasons not to prefer local food in catering businesses? 5) What are the future development needs to make a local food system more functioning and sustainable?

Following the Finnish Rural Policy Committee (2000), "local food" is defined in this paper as food produced and consumed by exploiting the raw material and production inputs within the region, promoting the economic development and employment of this particular area, which may be a municipality, province, or economic area. "Local food system" is defined as a local food supply chain based on the exploitation of the local or regional products and short supply chain. That is, the physical and temporal distance between the production, distribution, and consumption is as short as possible.

The paper is based on the empirical study that was carried out as a qualitative case study focusing on the relations between rural food suppliers and catering businesses. This paper presents some results of the case analysis. The study is part of a three-case study, where the two other parts will concentrate on the local food chains between rural food processors and rural tourism enterprises and rural food processors and retail stores. The study was partly financed by the Finnish Ministry of Agriculture and Forestry.

The paper is organised as follows: the theoretical background is reviewed and briefly discussed in Chapter 2, and the input data and methods are described in Chapter 3. The most important results are examined in Chapter 4, and Chapter 5 presents a discussion and the conclusions. The study is presented in more detail in the research report by Paananen and Forsman (2001).

Theoretical background

The theoretical foundation for the study lies both in the value-based theories and supply chain management. "Local food" is looked upon as the potential source of value for the different actors in the food chain. "Local food system", in turn, is considered as an alternative pattern of food supply for the more conventional industrial type of food supply (see Marsden, 2000). Following Marsden et al. (2000), in the alternative food supply chain approach, a great deal of emphasis should be laid on the type of relationships between the producer and customer rather than the product itself, as well as on the role of this relationship in creating value. Consequently, we combine the ideas of the value-based thinking and supply chain management in order to see how a small local food supplier could establish a favourable position on the local food markets.

Customer value creation is a prerequisite for competitive advantage (Slater & Narver 2000). In this paper, the local food product and local food system is seen as a potential source of competitive advantage for a small rural firm. However, to base their business on locality, local food, suppliers need resources and competencies, one of the most important of which is an understanding of customer value. Customer value, in this context, refers to the value that customers perceive to get when using local products and purchasing products through a local food chain instead of using non-local national and imported products acquired through conventional supply chains. Of utmost importance in today's value-based thinking is that producers should have a deep understanding of customers' own value creating activities (see Ravald 2001). Accordingly, trying to exploit local food as value added, rural food processors should understand and learn those benefits and consequences the use of local food will have in catering units. In this study, we approach customers' value creation on the basis of Woodruff's (1997) customer value hierarchy model and Kemperman and van Engelen's (1999) customer value mix model. In the customer value hierarchy model customer satisfaction is divided into attribute-based satisfaction, consequence-based satisfaction, and goal-based satisfaction (Woodruff 1997). In the customer value mix model by Kemperman and van Engelen's (1999) customer benefits, customer sacrifices, and customer risks are combined to result in a more holistic view of customer value.

In this study the understanding of customers' value creation is connected to the supply chain management. Supply chain management aims at the integration of balancing supply and demand across the whole supply chain, where efforts are made to bring suppliers and customers together in one simultaneous business process. Broadly defined, it covers all the value-adding activities in the entire chain (Omta et al. 2001, Tan 2001). The objective of supply chain management is to generate most value, not solely for a firm but for the whole supply chain network, including the end-user (Lambert & Cooper 2000).

In conventional food supply chains, the interdependence between different chain actors is usually organised sequentially; one actor's output is another actor's input. The value created from managing these transactions derives typically from reductions in transactions costs and logistics optimisation (Lazzarini et al. 2001). However, the distance from the producer to the ultimate end-user is often long (Nygård & Storstad 1998), both in space and time. Although the pursuit of transparency in the entire food chain is accepted as a common goal in conventional food chains also, this transparency such as the knowledge of product origin may be obscured when the product goes through several links before reaching the end-user.

In a local food system the chain is usually shorter in terms of number of chain actors or members, and the physical and temporal distances are considerably smaller compared to the traditional food chain. Moreover, we wish to emphasise explicitly the different kinds of interdependencies between the actors. Although the transactions between the actors in an alternative food chain are also vertical and thus imply sequential interdependencies, more important is the reciprocal interdependence between the different actors (see Lazzarini et al. 2001). This interdependence relates particularly to knowledge co-specialisation, which means that one actor is strongly dependent on the knowledge of another actor (Lazzarini et al. 2001). Therefore, we assume that to establish a functioning and sustainable local food system, the ties between chain actors should be strong and mutually dependent. Based on these ideas, Figure 1 presents a simplified illustration of an alternative way of viewing the food supply chain.

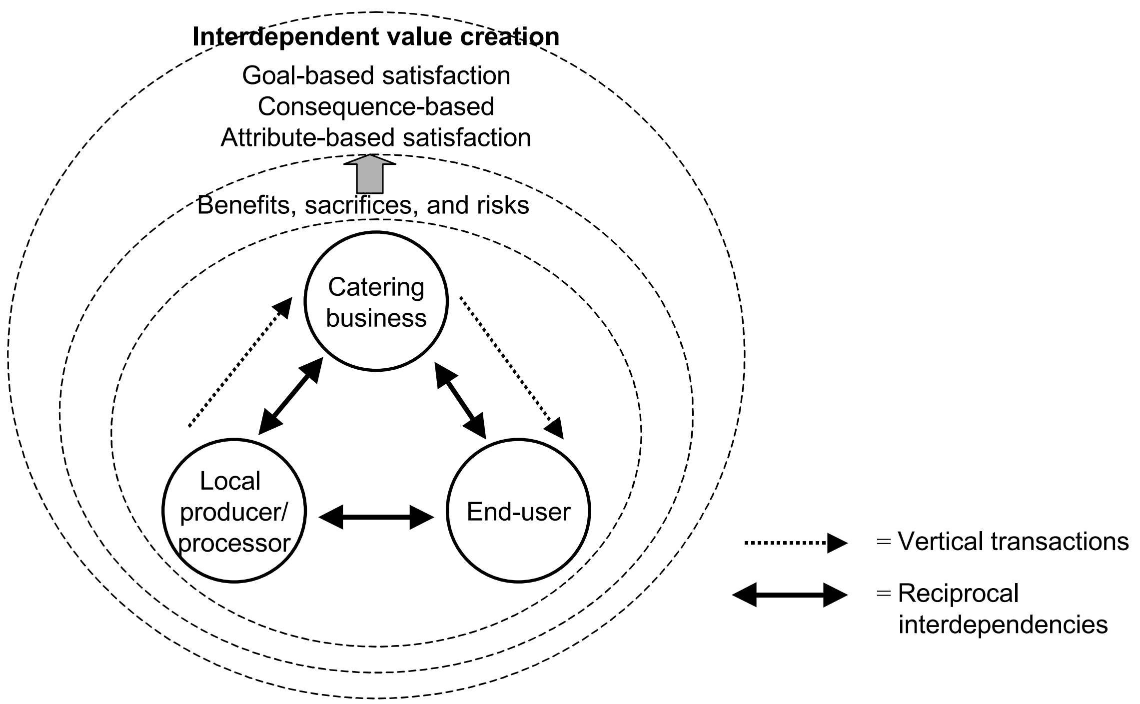

Figure 1 Alternative way of viewing the food chain

To conclude the theoretical discussion above, we assume that each participant in the supply chain benefits both from the local food per se and from the local food system between rural food processors and catering businesses. Straight and short food supply chains or networks are assumed to have a positive impact on the characteristics of a local firm's offerings and the buyer-seller relationship.

Methods

The study was conducted as a qualitative case study. A case study approach was chosen because the contemporary "local food" thinking is quite a new phenomenon in Finland and, owing to this, there are no scientific research results available. The study in this field is only getting started in Finland. Experiences from the use of local food have mainly resulted from are mainly the result of single local rural development initiatives and projects organised by local actors. Consequently, the case study approach (see Yin 1994, Stake 1995) makes it possible to take a closer look at the 'local food' phenomenon and consider it from a wide range of different perspectives in order to study its unique features and commonalities. The qualitative method was chosen largely for the same reason as the case-study approach. Especially, the understanding of the customer value hierarchy concerning the benefits of using local food would not have been possible without deep and detailed "why" questions and interactive interview situations.

The data were gathered through semi-structured interviews with 12 entrepreneurs and 9 representatives of institutional food service units and restaurants in Eastern Finland. Catering business actors to be interviewed were selected based on discretion. Six representatives of the latter group represented non-commercial food service units and three represented commercial restaurants. The sample of the catering units included three types of units with respect to use of local food. First, three units utilised local suppliers to a significant extent in their purchases and were involved in some kind of local food system. Second, three units purchased local products to some extent, but were willing to increase the co-operation with local actors. Third, three units used local suppliers occasionally depending on the available supply and had a more or less neutral position on local food, but would like to increase the use of local products if the firms were more active in providing them.

The entrepreneurs to be included in the sample were chosen among the existing suppliers of the catering business units involved in the study. The firms in the sample produce the following product groups: fresh and processed potatoes and vegetables, fresh berries and berry products, milling products, fresh meat and meat products, bakery products, eggs, and turnip rape oil. The sample included both farms and small-scale processors. Four of the firms produce organic products (fresh and processed potatoes and vegetables).

For the interviews, a theme framework based on our theoretical views as well as experiences from earlier development projects concerning local food was constructed. The theme framework for the entrepreneurs differed in certain respects from that for the representatives of catering businesses. The interviews of both actor groups were analysed separately. The data were grouped into themes following the frameworks. The main analysis was largely based on the customer value mix model of Kemperman & van Engelen (1999) and the model of customer value hierarchy by Woodruff (1997).

To ensure the reliability and validity of the research process and the results, a systematic procedure was used in the compilation and analysis of data (see Paananen & Forsman, 2001 for the details). Efforts were made to maintain the principle of the chain of evidence from conclusions back to initial research questions and from questions to conclusions (Yin 1994, p. 98) through the entire analysis procedure.

Results

This chapter presents some focal results of the case study. The interest in the use of local food in the catering units was strong. However, in the current situation, basing their meals solely on local products was not seen as realistic in many units. This is simply due to the fact that many product groups are not available in sufficient amounts by local suppliers. In many cases it is not possible, for instance, to purchase fresh meat and fish and products made of these using locality as the criterion because the supply is insufficient. Therefore, in many catering units the local firms are more or less seen as supplementary suppliers. Yet, the significance of local food and the role of local firms providing local products are expected to grow in the near future. Favourable geographical location with respect to customers, good product quality, locally well-known firm reputation, flexibility in adjusting the production or processing to meet the customers' needs, and strong customer relations are seen as general competition factors that help a firm to turn local foods into marketable products. This, however, requires that local firms are more active in offering their products on a more regular basis to the potential customers.

The meaning and value added of the concept "local food" for the rural firms and catering businesses were analysed. The use of local products has many economic (e.g. low delivery costs) and non-economic advantages (e.g. maintenance of regional food traditions) for both chain actors. The results show that the dimensions, consequences, and value of local food is perceived in a somewhat different way by the entrepreneurs (figure 2) and the representatives of catering businesses (figure 3). It seems that entrepreneurs look at the benefits of local food more from their own perspective as well as from the social and regional perspective than in terms of customer value creation.

The study also showed that there are many reasons not to prefer local food, which may constitute serious impediments to the realisation of local food systems from the point of view of the catering businesses. The most significant aspects are: (1) local suppliers' too small production volumes and inadequate resources to meet the demand of the catering business, (2) price level too high, (3) too much time consumed at the food service units in searching for new local products and creating new business relations, and (4) the risk relating to reliability and regular deliveries concerning the new relationships.

Based on the data, four aspects to develop local food systems from the point of view of the catering business can be brought out. First, close and active co-operation in product development between catering units and firms is an absolute prerequisite. Catering units should be more open towards the local producers about their specific needs. Long-term co-operation extending far into the future is needed. A producer needs to know in advance, for example, which potato variety should be planted in the spring, i.e. which characteristics of potatoes are important for the use in a particular kitchen. Furthermore, there is an increasing demand for pre-processed products such as pealed and sliced potatoes. Second, co-operation in storage is needed. The storage facilities of catering units are often quite limited, and thus there is a need to develop storage in the local firms. For example, there would be demand for the local or at least domestic berries all year round, but there is not enough room in catering units to freeze berries for the whole year. Third, firms should be able to guarantee the reliability of the deliveries in the long term. Catering units would purchase more local products if these could be supplied on a regular basis. Fourth, logistic issues have to be solved. Local firms should co-operate in product deliveries, invoicing, etc.

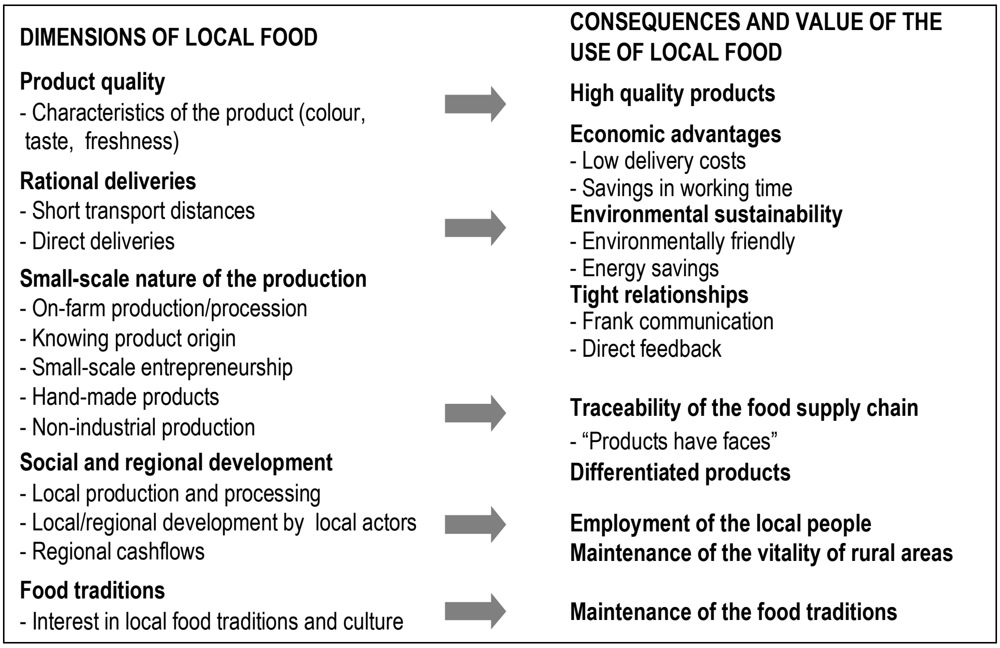

Figure 2 Dimensions, consequences, and value of the local food from the entrepreneurs' viewpoint

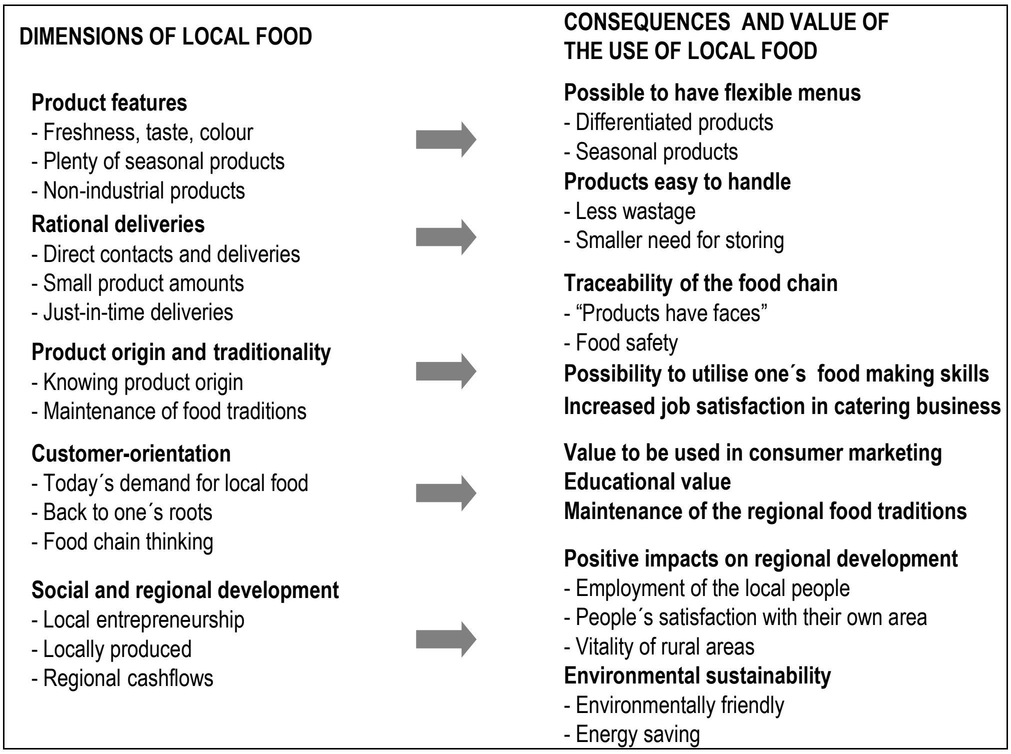

Figure 3 Dimensions, consequences, and value of the local food from the catering businesses' viewpoint

The results also revealed that in the catering units organic products were often associated with local food. However, especially the entrepreneurs not supplying organic products were somewhat confused about this issue. They feared that if the catering business units systematically considered only organic products as local foods, they would be outcompeted by other suppliers. They stressed that local food and organic food is not the same thing and the concepts should be kept apart.

Discussion and conclusions

Based on the case study results, we see that there really is potential for a systematic emergence of local food systems and shorter food supply chains in the future. In the study efforts were made to understand the local food as a phenomenon and to examine some experiences from shorter supply chains and future development needs. Because of the case study approach, the results, however, cannot be generalised to the population as a whole, but we wish that they could promote the development of local food systems in rural areas. Consequently, we hope the results will be applied widely by rural entrepreneurs in their strategic decisions, catering businesses, training and advisory organisations, as well as by-national and local policy makers and other local actors.

The results support our basic assumption that both parties of the chain included in the study benefit from the use of local foods and food systems. Using local products provided by local actors may result in both economic and non-economic advantages for the catering businesses. It is noteworthy that many non-economic aspects may turn into economic advantages, at least in the long run. For instance, even if the unit price for the local vegetables would be higher compared with vegetables purchased through conventional channels, the smaller amount of wastage due to the local just-in-time deliveries may result in lower total costs in the long term.

Still, much needs to be done to make a local food system a sustainable model. Fundamental questions, which need to be solved in this context, include how to make the small local food suppliers more customer-oriented and how to increase their willingness to co-operate. It is obvious that the farms and food processing firms should become more customer-oriented to meet the customers' needs. According to the results, the value added to local food is valued to a different extent by the local suppliers and the catering businesses. This may prevent the development of an efficient local food network between the partners. Therefore, it is important for local suppliers to be conscious of the fact that to meet the customers' needs requires a deeper understanding of the customer value creation process. Thus, it is not enough just to find out those physical product attributes that the customers expect from local products, but rather to understanding of the consequences the use of local products may have in different situations and the primary goals the customers pursuit through the use of local food.

Co-operation plays a crucial role in the supply chains where the relations are mutually dependent. On one hand, co-operation is needed between a local supplier and a catering unit. Co-operation in product development is particularly important in order to produce and process products that bring satisfaction in the use situation (e.g. the best potato variety). In the co-operative product development, feedback from past transactions and joint problem solving is crucial. On the other hand, small food suppliers should be more active in co-operation with each other. Co-operation is needed especially in logistics. Customers should have a possibility to order products from several local suppliers by the same order. Also, joint deliveries and invoicing should be used. Improvements in logistics would help to eliminate the non-value-added costs as well as to decrease the time spent on orders and deliveries at the catering unit. This, however, calls for the establishment of joint ventures or other forms of co-operation between local suppliers.

The difference between the concepts of local food and organic food should be highlighted to all actors within a local food supply chain. It goes without saying that only locally produced organic food is local food, but in general local food does not need to be organic. However, to combine local and organic dimensions, an "organic local food" label could be created and locally produced organic food could be marketed under this concept. Whether this would lead to even more confusion is another question.

Local actors, including policy makers, representatives of the private and public sector, media, etc. also have a great responsibility in promoting the emergence and development of alternative food chains. A positive attitude towards local food and seeing its broader meaning for the local society is likely to result in more sustainable development projects concerning local food. Moreover, changes in the official purchase tender practices are definitely needed. In the catering units kept up by the public sector, official purchase tenders that are largely based on price offers by potential suppliers should be replaced by a wider range of purchase criteria, allowing the purchases to be based on aspects other than price alone (e.g. locality, environmental considerations).

Finally, we would like to stress that we do not associate the conventional supply chain with 'bad' and the local one with 'good'. Instead, we wish to emphasise that today there is demand and room for different models of food supply chains, where both the conventional industrial type of food chains and alternative food governances are needed, and both of them can benefit and find support from their co-existence.

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Ruralisation – Integrating Settlements and Agriculture to Provide Sustainability

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Abstract

To fulfil the basic goal of delivering food for the tables of the citizens, modern western agriculture is extremely dependent on supporting material flows, infrastructure, and fossil energy. According to several observers, fossil fuel production is about to peak, i.e., oil extraction is no longer capable of keeping pace with the increasing demand. This situation may trigger an unprecedented increase in fossil energy prices, which may make the current highly energy dependent food production-distribution system highly vulnerable. Also, the supply of phosphorus, a key factor in agriculture, may be at stake under such circumstances. The paper analyses this situation and discusses settlement structures integrated with agriculture that might increase food security by reducing energy demands.

In the proposed societal structure, agriculture is integrated with settlements, most of the food needed by the population is produced locally, and the nutrients for food production are recycled from households and animals by means of biological processes demanding considerably less mechanical investment and fossil support energy than the conventional type of agriculture.

Key words*:* agriculture, energy supply, energy efficiency, fossil energy, nutrients, settlement structure, vulnerability.

Introduction

Contemporary Swedish agriculture is one of the most technically advanced and successful in the world. The development of agricultural practice has led to a situation where a very small part of the population (1997: 0.72%, (SCB, 1999)) is employed in agriculture. However, this situation has been achieved only by a large amount of external support, (Giampietro, 1992). Agriculture has changed from a local activity to a throughput business (Goodland & al, 1992) that is dependent for support upon societal functions, energy sources and minerals derived from the wider world.
To survive and maintain food production for the population, current western European agriculture needs continuous support by the following:

- Reliable and cheap fuel production that can continue in the future.
- Availability of phosphorus ores that can be extracted to produce fertilisers.

- A distribution system for fertilisers, animal feed, fuels and agricultural products that functions irrespective of disturbances in the society outside the agricultural system.
- A support infrastructure that can provide renewal and repair of machinery, independently of the general industrial climate and future energy prices.
- The agricultural system is heavily dependent on services that are often taken for granted, e.g. constant low energy prices.

Therefore, when discussing a sustainable agricultural system, it is important to include the necessary support systems for the entire chain.

The ultimate objective of agriculture must be the provision of food for the human population. However, some of the mentioned supports associated with this kind of agricultural production are so vital that any failure, such as an unexpected energy price increase, can turn the success of agriculture into disaster.

This perspective paints a gloomy picture of the sustainability of this highly productive agriculture and of any society that depends on it for its subsistence. The aim of this paper is to discuss the capacity and reliability of the support system as it is designed today, and, in cases where this capacity and reliability appear doubtful, to discuss how problems might be alleviated.

The dependencies

Dependency on material and industrial energy support

Pre-industrial agriculture was a highly local activity. Most machinery was made locally, and agriculture was based mainly on different types of locally captured solar energy. Nutrients were collected by means of meadow plants and transported to the fields through harvesting of winter feed, or with manure from grazing animals brought home overnight. The necessary energy for these activities was exclusively derived from the sun, which therefore limited the energy use in these activities. Often, the energy used was considerably below this input, i.e. having high efficiency (Jansén, 2000).

The main energy input into modern agriculture is not solar energy but industrial energy of different types. Parallel with the need for constant input of other necessities, i.e., fertilisers, biocides, animal food, plastics for silage and drugs for treatment of animal diseases, it gives modern agriculture an operational structure similar to a throughput industry. The increased yields experienced by these methods are not due to increased ability of the crops to obtain more solar energy, but rather that some tasks formerly done by the crops (e.g., extracting nutrients and restraining diseases and herbivores) are done by the farmer using fossil energy, which accounts for the increased grain yield (Odum, 1971) figure 1.

This strategy is not limited to plant crop production, but can be found in most agricultural and food related activities, as animal husbandry, fish production and fishery. Thus, in order to boost the rate of output, a constant throughput of energy and materials are applied. This makes agriculture highly dependent on different types of industrial support for maintenance, and energy and nutrient requirements. Therefore, in this type of agriculture the energy input often equals or exceeds the output (Odum, 1971; Hall, 1992; Hoffman, 1995; Jansén, 2000).

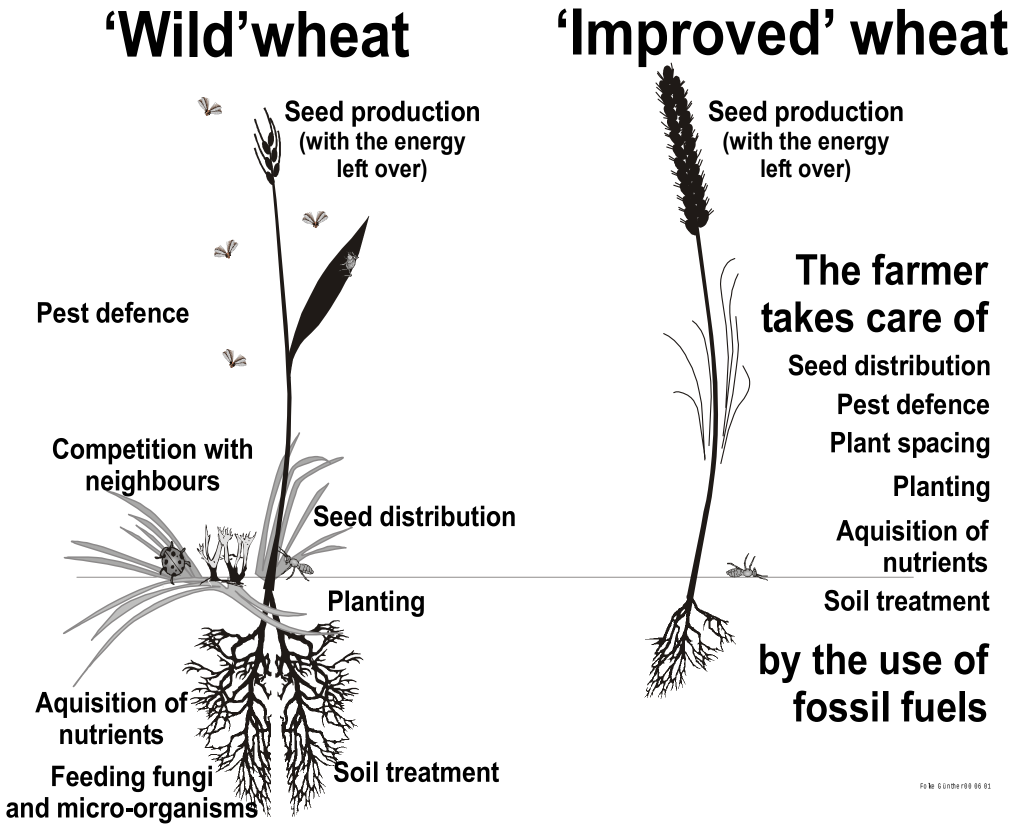

Figure 1 The improvement of domesticated plants and animals has often implied an increased dependency on fossil fuels

To produce food, today's agriculture in developed countries is heavily dependent on fossil fuels. The input of fossil fuel energy often equals, or surpasses, the output of food energy for human consumption (Hall et al., 1992; Folke & Kautsky, 1992; Hoffman, 1995), suggesting why industrial agriculture can be referred to as a black box for converting fossil fuel energy into edible food energy. The ratio of energy input/output of Swedish agriculture is about 0.96 including fodder for pet horses (Hoffman, 1995), which is in close concordance with this 'black box' description.

This relation is further highlighted in a note by H.T. Odum in the Energy Resources list[1] in Sept. 2000:

Because of its large content of environmental and fuel emergy, agriculture contributes much more than is paid for its products. At a time when agriculture was 7% of the Texas economy on a dollar basis it was 35% of the Texas energy budget. So-called agricultural subsidies are justified to sustain this bonanza.

[1] http://groups.yahoo.com/group/energyresources

Swedish agriculture uses over 110 litres of liquid petroleum per hectare per year (SCB, 1994). To this must be added the indirect use of fuel for production of pesticides, fertilisers, machinery etc., which can easily be 50% of what is directly used, and, on top of that, the requirements for electricity.

Vulnerability of the food production system

Often, the material use in our society is not questioned. Plans are made as if resources needed could be multiplied just by increasing their price. However, for storages this is not true. The distance a car will go with a full tank is not related to the price you are willing to pay for the gasoline. In the current society, we are heavily dependent on storages of energy and nutrients. This limits the sustainability of the society to the time of extraction of the storages.

The energy and nutrient use for agricultural production have a tendency to increase to the limit that the price of the input is close to the price of the output. As long as energy is cheap, it is possible to put in far more energy in the production than the content of the produce. Today, the energy price for energy used in the production is less than a tenth of the price for the energy in the produce, which makes this conduct possible.

However, calculating the ultimately recoverable oil from the amount discovered and comparing this with the cumulative extraction, reveals that about half the reserve is used (Deffeyes, 2001). This implies that the current low energy price is highly unstable.

Increased energy prices will also increase price for fertilisers. Since the strategy in mining practice is to extract the least energy demanding resources first, those left will demand more energy for extraction. This is a highly ominous strategy in times of expected increased energy prices. The reserve of phosphorus allows extraction for about 100-150 years at *current* energy prices.
To avoid these threats, recycling nutrients and diminishing the energy demand in food production and processing seems to be a prudent strategy. (This discussion is extended in Günther, 2001).

Transport dependent centralisation

With fossil fuel based industrialisation and its associated infrastructure development came the capacity for far-away production and cheap long-range transportation. This created the possibility of concentrating people in urbanised – industrialised areas. There seems to be a close connection between the availability of cheap energy and urbanisation. Without cheap energy, large cities cannot be sustained. The extraction, refinement and transport of necessary products would otherwise be too expensive, not to mention the recycling of nutrients necessary for sustainability (Günther, 1998b).

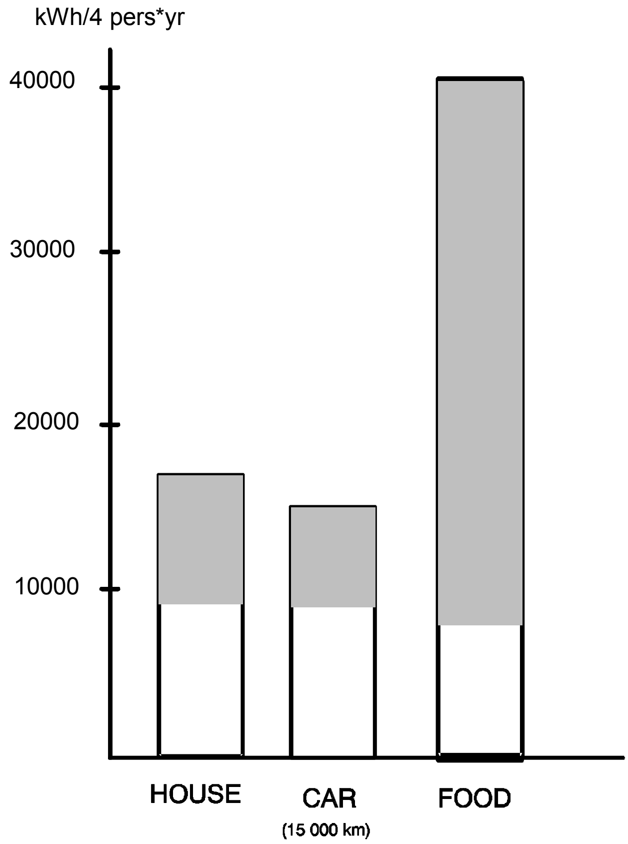

Figure 5 The energy use of a family of four in Sweden, roughly calculated. The single largest energy user is the food system. Here is also the largest potential for increased energy efficiency (grey part of the bars) to be found

A general principle of self-organising systems is to change in a direction that enables the system to degrade more available exergy (Schneider & Kay, 1993). This principle can explain the substitution of machinery for manual labour, or the transportation of food instead of local production. The availability of cheap energy can thus, to a fair extent, explain the growth of cities, just as it gives clues to other types of centralisation, for example the specialisation of agriculture into large units. Low-cost energy development has led to a situation where single households can be associated with large uses of cheap energy:

The house

In Sweden, a normal new-built house for a family of four, built according to the Swedish building standards of 1980 can be assumed to have a yearly energy use of about 17,000 kWh. However, by applying energy conservation it is possible to reduce this figure to below 10,000 kWh. The potential for increasing energy efficiency of the building is thus about 8,000 kWh/year for a family of four.

The car

Another large energy user of this four-person family is the car. Assuming an average use of the car to be 15,000 km/year, using 0.6 - 1 litre of gasoline per 10 km. A more energy-efficient car uses about 9,000 kWh of gasoline/year, a less efficient car about 15,000 kWh. Assuming the same indirect energy use in construction and maintenance, the difference is about 6,000 kWh/year. Thus, the potential for increasing the energy efficiency of the car is about 6,000 kWh/year, i.e. in the same size range as for the house.

Food

The energy used for food transportation and handling is, to a large extent, an unacknowledged part of the total per capita usage of energy. In Sweden the use of direct energy for transport and handling of food is conservatively estimated to be about 10% of the total annual energy use (Olsson, 1976). Nils Tiberg (Professor at Luleå Technical University, pers. comm.) estimates the figure for Sweden to be about 60 TWh, or 13% of total energy use. Including the energy expenditure in agriculture which is in the region of 1:1, the total energy efficiency would have been about 8:1 in 1976. Considering the changes in society during the last 20 years, this figure would be worse today. A guess that it is more like the US in 1975, 1:10 (Hall & al, 1986), would not be in excess.

It can thus be estimated that the YPE (Yield Per Effort) in food production, transport and handling is about 0.1. This implies that about ten energy units are spent for each energy unit delivered to the dinner table. The average food energy needed for a person is about 1,000 kWh per year. A conclusion of this is that for a family of four, about 40,000 kWh/year is needed for food. This is clearly the largest single energy use.

Assuming a Swedish agricultural system similar to the one today, but with more local handling and managing of food, the energy expenditures for the production of food necessary for feeding this family would be about 4,000 kWh in agriculture itself and an equal amount of energy for a 'local' supply system. In this case, the potential for efficiency increase would be about 32,000 kWh (Figure 5).

Discussion

The question has been raised whether the importance of liquid fuels has not been overstressed in this article, and whether increased energy efficiency could not do.

Consider Figure 5. Here, the energy use of a family is broken down into the general components: house, car and food. The grey parts of the bars are estimated decrease due to increased efficiencies. In the first bar, the house, a large part of the total energy use could come from biomass, solar collectors, photovoltaics and the like. Together with an increase in the efficiency in the construction of the house, an increase in the price of fossil fuels doesn't seem to be detrimental for the possibilities of providing energy for housing.

The car, however, seems to be more vulnerable. Most of the cars today are propelled by means of *liquid* fuels. Attempts have been made to propel them with electric batteries, fuel cells and the like. Since these not are fuel *sources*, but only fuel *carriers*, this changes the question into how to find power to load these carriers, whether with solar energy or other, fossil, sources submitted to the same problems as mentioned for petroleum in this paper. Providing personal transportation in the same scale as today with renewables and solids seems to be difficult, but not completely impossible. The energy use for personal transportation might, however, be diminished by decreasing the *need* for transportation, such as distance working, decentralisation of working places and the like.

The food production and transportation, however, is the largest single energy demand, today nearly entirely dependent on liquid fuels and, to a lesser part, electricity. To this comes the problem of recycling the nutrients, which is necessary for long-time survival. It is hard to imagine a transport system that would accomplish this with a considerably lower energy demand. In this case, increased energy efficiency seems to be the solution. This is what the last part of this paper is about.

Potential solutions

In this part of the paper I will suggest some measures that could be taken in order to alleviate the problems of high risk and potential instability of the food supply system. Some benign side effects that can be expected from the alleviation measures will also be pointed out. I will not discuss measures taken within the agricultural system itself, such as, for example, organic farming or agroecology, since such measures have been discussed extensively in the literature (e.g., Altieri, 1987; Pimentel, 1989). Instead, I will focus on the alleviation of the problems that have arisen as effects of access to cheap fossil energy.

1. Minimising energy use in transportation

The heavy dependence on transportation in current food production system can be ascribed to two or three infrastructure modes:

- Fertilisers and other support material for the agriculture are externally produced, often very distantly.
- Agricultural sites and end-user of food are separated, often spatially very separated.
- Animal fodder is commonly produced in a part of the country different to where it is needed.

These transportation dependencies could be diminished radically by a closer spatial, and social, integration of agriculture and settlements, together with a re-introduction of a balance between animal husbandry and plant production on individual farms (Granstedt and Westberg, 1993). The discussion in the first part of this paper indicated that today about 10,000 kWh*p^{-1}*$year^{-1}$ is used for food delivery. However, it is possible to imagine a decrease of this figure to 2,000 kWh through the closer integration of agriculture and settlements, combined with a strategy for local food production. If this were possible for 50% of the Swedish population, the amount of energy saved is about 40 TWh annually, which equals the electricity production of eight nuclear powered reactors.

Energy use can, of course, also be diminished by different intra-farm technological changes to diminish energy investments in agriculture, which is currently of the same order as energy input in food. Increased efficiency of intra-farm energy use can, however, not be expected to lessen the total energy use more than by a small part of the industrial energy subsidies used in agriculture, which is about 18 TWh in Sweden (Hoffman, 1995).

Increasing nutrient circulation

In modern agriculture, the nutrients lost via export are replaced by new ones, supplied from mineral ores (P, K) or from industrial processes (N). However, this increases the vulnerability of the food system due to the connection with the mining and processing industry and the earlier mentioned problems of materials and YPE.

Natural biological systems, e.g. ecosystems, offset the problem of source deprivation of essential nutrients. They respond in two ways: For elements that have volatile phases (e.g. C, N, O, S & H) supply is by atmospheric transport. For elements that in practice have no volatile phases, repeated cycling solves the problem. Advanced ecosystems are able to nearly eliminate leakage through export of nutrients (Stark & Jordan, 1978; Odum, 1973, 1985; Kay, 1994). Therefore, in order to augment sustainability, it seems appropriate to imitate the strategies of long-time sustainable self-organising systems. One of the most important of those strategies appears to be "cyclic charging - discharging process" of simple elements, the regenerative cycle (Günther & Folke, 1993; Günther, 1998a). In ecosystems, such elements are volatile (N, C, S, O, H) and non-volatile (P, K and trace metals). The limiting ones, such as nitric oxides and phosphorus, are carefully recycled in such systems (Stark & Jordan, 1978; Odum 1973, 1985; Kay 1994). To attain ecosystem mimicking (ecomimetic) nutrient circulation, two changes are needed in current agricultural practice.

- Animal feed has to be produced on the same farm, or in the vicinity, allowing the manure to be returned to the land where the feed is produced. By this practice, 60-90% of the nutrients, at least the non-volatile ones, can be circulated (Granstedt and Westberg, 1993). Nutrients with volatile phases, e.g. nitrogen, can be conserved by anaerobic storage, effective mixing into the soil or other means.
- Nutrients actually exported as human food should be returned as uncontaminated as possible, preferably as human urine and (composted) faecal matter. With the use of source-separating toilets, which do not mix urine with faeces, the urine, containing most of the phosphorus and the nitrogen excreted (Günther, 1997), can be easily reclaimed. The faeces can be composted out of reach of flies for six months to a year in order to eliminate pathogens before returning it to the fields (figure 6).
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Integration of agriculture and settlements
Most of the problems pointed out in the first part of this paper can be ascribed to the unintentional separation of agriculture and settlements that developed as a side-effect of "the industrial revolution" over the last hundred years. Re-integration of agriculture with settlements would be one way of solving the problems of increased vulnerability and decreased sustainability of the food system. Many of the environmental problems experienced today might also be alleviated by this strategy. Such a restructuring would also increase the ecological qualities of the society.

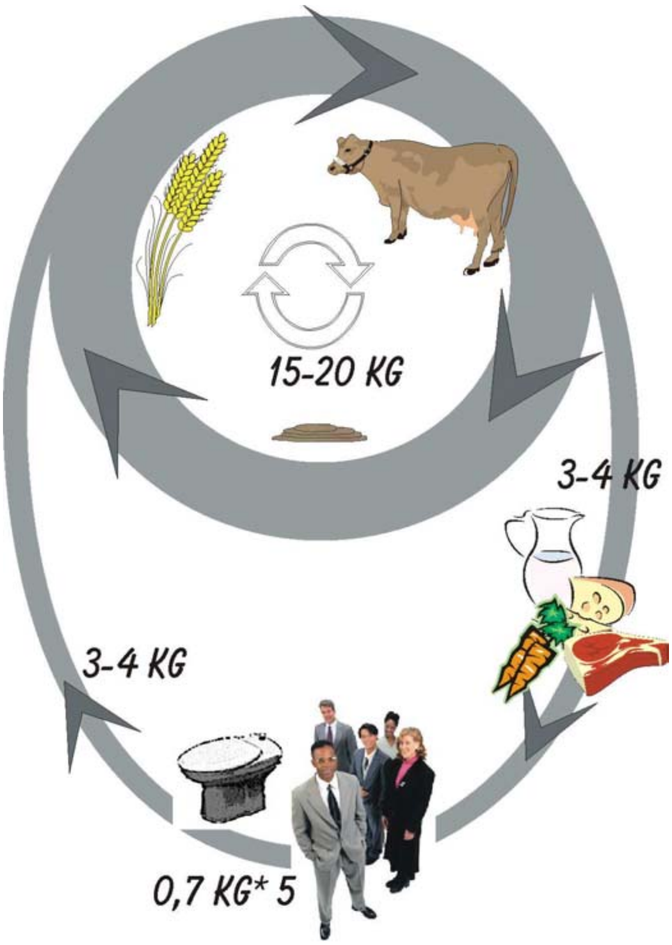


Figure 6 The phosphorus demand for a hectare of balanced agriculture (i.e. one producing food for its animals) can be maintained by the reclamation of nutrients from 5-7 persons. This implies that one such person needs about 0.2 hectare for the production of the annual food needs. (The dimension of the figures on the picture is *phosphorus per hectare*)

Alleviating the problems at different scale-levels: Micro-scale – The balanced settlement

It is also necessary to study different hierarchical levels (Allen & Starr, 1982). I will first try to outline an example of how some of the identified problems can be solved on the scale of a single agricultural unit and a simple small settlement (around 200 people).

Elimination of dependency for feed and nutrients

Assume an agricultural unit that produces both animal and vegetable products. Suppose further, that all the feed for the animals is produced locally. This will reduce the need for import of nutrients by 60-90% (Granstedt and Westberg, 1993). However, the export of essential nutrients in food will still amount to 3-4 kg P*ha^{-1}*yr^{-1}. For long-term survival of the system, this amount must be recycled. A human generates about 0.7 kg P/year in urine and faeces. This means that the phosphorus content of the excrement from 5-7 people equals the losses of phosphorus in food from one hectare of a balanced agriculture (figure 6). From these figures, the area of balanced agriculture needed to support one person is obtained. This area is between 0.23 and 0.15 hectare, which is in agreement with the figure of 0.2 hectare per person calculated from the need of food for a person and the production capacity of an average Swedish farm (Günther, 1989). A 40-hectare farm can thus support about 200 people for a majority of their food needs.

Thus, to diminish the acute dependence on external support of nutrients, integration is needed between the production of animal fodder and the use of animal manure, and the local settlements with the agriculture as a food producing system. This integration also implies diversification of agriculture because of the diversity of products needed by the population.

Elimination of leakage

The direct leakage of phosphorus, which in this article is chosen as a 'standard' nutrient from an agricultural unit, is within the range of 0.2-0.4 kg*ha^{-1}*yr^{-1} (Brink & al., 1979). By the opening water courses and re-planting of buffer-strips, a large part of this leakage can be captured (Mander & al., 1991, 1994). Examples of reclaiming methods for the nutrients contained in the biomass would be compost, biogas sludge or ash. Such buffer strips also have other functions than the capturing of nutrients. In windy conditions, they also have a wind shielding function, increasing the yield by 15-30% within 15 meter from the vegetation strip. Other benefits of such vegetation are the increased occurrence of predators against insect pests (Andersson, 1990) and bumble bees for pollination (Hasselrot, 1960).

Economy

Another problem already noted above is the low and decreasing income of farmers. The extensive handling and transportation system between the producer and consumer is not only energy intensive, but also appropriates a large part of the price for food paid by the end-user, more than 75% (calculated from the figures in LES, 1991, 1993a, b). Furthermore, the income received by the farmer largely covers the cost of financial and material inputs paid by the farmer, which is about 85% calculated from the figures of Augustsson and Johansson (1995) (figure 7).

With an increased integration of agricultural units and settlements, direct trading between the farmer and the consumer becomes possible. If the farmers were given half the price for food that is paid by the consumer today, this could increase his income five to six times. The consumer could also reduce the cost for the food produced by the farmer by about half, both figures assuming that the product price to the farmer is 25% of the consumer price (a figure that is somewhat high).

Today, the farmer's earnings are 15% of his income (Augustsson and Johansson, 1995), which represents not more than 3.6% of the market price in the shop. Assuming that the production cost would increase by 30% because of the increased diversity in agriculture, a fifty-fifty agreement between a farmer and a local settlement would still increase the payment to the farmer from 3.7% of the shop price to 22%, or about six times. A rise in farmer income of that magnitude can be expected to enforce even large changes in agricultural practice.

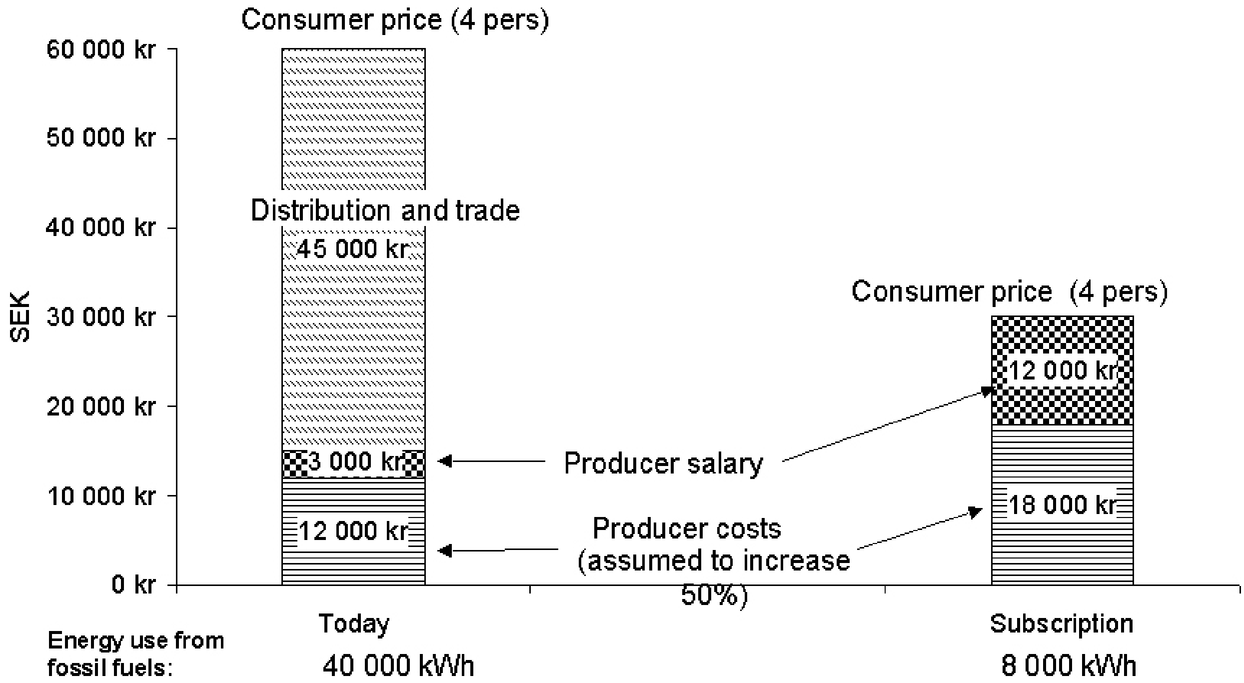


Figure 7 A direct co-operation between an agricultural unit and a local settlement would be economically favourable, not only for the consumers, but also for the farmer, even if the production costs would increase by 50%

Medium scale

The implementation of the above-proposed solutions is compatible with intermediate size settlements. Three or four settlements with their associated farms can form groups of 800-1,200 persons and an associated agricultural area of 160-240 hectares. If the areas are also used for the improvement of local ecosystems, 170-260 hectares can be expected to support these people. This population size is large enough for the establishment of a common social infrastructure, such as primary schools and small service business. However, it could be argued that this size of settlement is not enough for non-agricultural production, such as cultural needs and service provisions, and that this may generate an increased need for transportation. For the sake of discussion, however, imagine an area where such settlement types cover the land. In such an area, not regarding the incidence of lakes, mountains etc., there would be a population density close to 500 p/km^2, which might be enough for a diversity of direct social interactions, although not the amount we are accustomed to in high-density urban areas.

Large-scale implementation of the proposed solutions: Ruralisation

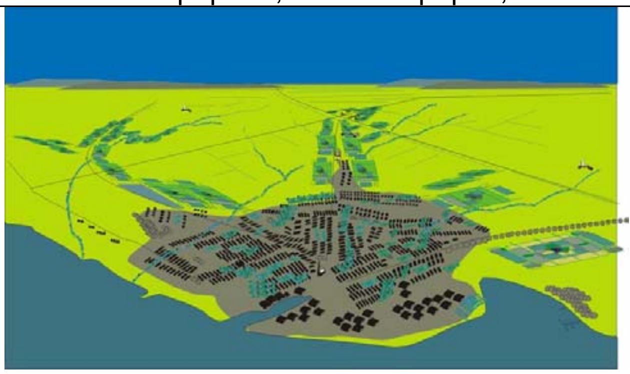
Nutrient circulation becomes increasingly expensive with increasing spatial distribution ranges (Günther, 1998b). The energy requirements for distribution of food also tend to increase in quantum leaps when the distribution pathways require extensive packaging and preservation of the products. As pointed out earlier, solving these energy requirements by means of fossil fuels increases the vulnerability of the society above the level needed if only basic provisions are made for human and environmental security. The only solution left, if the goal were this security, would be to maintain basic energy flows from renewable sources, i.e. solar, and reduce the external energy requirements for all sectors to the lowest level possible.

The means of providing agriculture with its "ultimate" raw material, phosphorus, would also need change. A system of linear flux of phosphorus through society over a prolonged time is both wasteful and insecure. Therefore, to attain nutrient circulation and at the same time reduce energy support requirements in large societies, a different strategy of societal structure should be chosen: The current trend towards increasing agricultural specialisation combined with urbanisation should be replaced by a closer integration of farms and settlements.

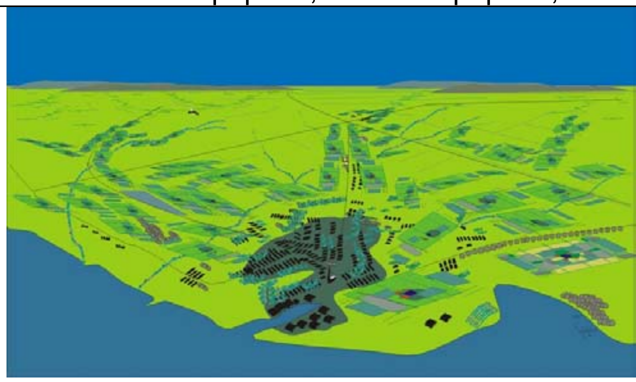
A name for such a strategy is *ruralisation*, as opposed to urbanisation. This development strategy implies a successive replacement of houses in need of extensive restoration or rebuilding. Instead of building new houses in existing urban areas, small settlements integrated with agriculture as outlined above would be created in the hinterland of the urban areas. Many of the problems discussed here could be alleviated by this strategy.

Year 0. Urban pop. 33,000 Rural pop. 3,000

Year 12. Urban pop. 24,000 Rural pop. 12,000



Year 25. Urban pop. 12,000 Rural pop. 24,000



Year 50. Urban pop. 3,000 Rural pop. 33,000

Conclusions

In this overview, I argue that agriculture is afflicted with a lot of structural problems that cannot be alleviated by further rationalisations of agriculture along current lines, for food system problems reflect general structural changes of society. They must be resolved by new structural solutions as outlined.

- The problems include:
- dependency on stored energy support
- constant input of nutrients and other materials from storage
- inescapable loss of nutrients, which is an effect from
- linearity of the nutrient handling system
- They are aggravated by the following factors:
- ongoing specialisation of agricultural units
- decreasing population working with agriculture
- urbanisation
- a dependency on inexpensive energy
- a probable increase in fossil fuel prices

I have argued that these problems, as well as others, could be alleviated by a gradual transformation of settlement systems called "ruralisation" and a closer integration of agriculture and settlements, this would:

- minimise dependency on industrial energy
- increase nutrient circulation
- increase integration between agriculture and other social activities
- increase and support ecosystem services received

The economic and sound benefits of such systems may well seem to be considerable, especially given the anticipated price rises and vulnerability of modern industrial agriculture. If one reflects more deeply on recent information on future access to fossil fuels, it is hard to conceive of a sustainable society that is not principally powered by solar energy and thoroughly recycle limiting nutrients.

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Urban agriculture and sustainable urban development

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Taking stock

At the beginning of the new millennium we live in a world of unprecedented human numbers. There are currently about 6.3 billion people, and this figure is expected to increase to some nine billion by 2050. About half of the world's population live in cities, a figure which is likely to grow to two thirds by 2030. Most cities are being built on farmland, a factor that will certainly reduce the world's food production capacity unless city people produce significant proportions of their own food. So some important questions need to be answered: Can the global environment cope with this "age of the city"? Will there be any untouched natural systems left? How can the world's growing numbers of city people be fed?

A very useful methodology in this context is to measure the "ecological footprint" of cities, drawing on the work of a Canadian ecologist William Rees and his Swiss colleague Mathis Wackernagel. As they see it, we need to quantify the land areas required to supply cities with essential resource services - the footprints of cities. These consists of three main components: the surface areas required - 1) to feed cities; 2) to supply them with forest products; and 3) to reabsorb their waste, and particularly their carbon dioxide output.

Using this method, I have tried to assess the ecological footprint of the city where I live: London, which has a population of just over seven million. I found that it extends to around 125 times its own surface area of 160,000 ha, a total of 20 million ha. This breaks down as follows: London requires about 1.2 hectares of farmland per person, a total of 8.4 million hectares, or around 40 times its surface area. The forest area needed to supply it timber and paper is about 768,000 ha. The area that would be required to sequester its annual output of about 60 million tonnes of CO_2 is by far the largest - about ten million ha, or half the total footprint.

A key issue here is how world-wide urbanisation and growth in affluence will increase human demands for land surfaces. It has been estimated that if developing countries copy our western urban lifestyles - in terms of demands for food, forest products and energy - we will need three planets, rather than the one that we actually have. It's of crucial importance, therefore, for cities in developed countries to become much more efficient in the way they use resources, and that certainly includes their food supply. Urban agriculture can make a crucial contribution here.

But here we are primarily concerned with the land area required to feed large cities such as

London, and the fact that food now tends to come from further and further afield.

London, of course, was the world's pioneering mega-city. It grew from just under a million people in 1800 to about 8.5 million in 1939, a city of an unprecedented size. At first London drew on a largely local food supply. But new transport technologies made it possible to bring its food in from further and further away. Steam ships supplied grain from Canada and the United States, lamb from New Zealand, wine from France and Italy, oranges from Spain and Brazil, bananas from the West Indies and South America. Today food is brought to us from just about anywhere - no longer just in freighters and trucks, but also in airplanes flying in from half way across the world.

Energy and land use

The location of Heathrow airport used to be London's market garden. Its sandy soil is very suitable for vegetable growing. Today, even though it is largely concreted over, Heathrow is still London's a major food supplier, but in a rather different way: food is flown in from across the globe. Such a global harvest offers us great culinary variety, but it requires the availability of vast quantities of fossil fuels. By the time food that has been air freighted for thousands of miles reaches a London dining room table, it will have used hundreds of times as much energy as the calories it actually contains. But not only air-freighting food is tremendously energy intensive. Frozen fish from the Atlantic contains some 100 times, meat from UK farms 50 times or more energy than its calorific value. These are astonishing figures. In seems unlikely that we can sustain such a high-energy food urban system for long.

But it is not only the energy input into our food system that should concern us, but also its global land use impacts. Increased demand for meat, in particular, has become a primary cause of deforestation in virgin forests in the Amazon, Thailand, Malaysia and Indonesia. Animal feeds such as soybeans and manioc produced in these places have been used extensively in Europe and Japan for many years. Now economic and urban growth in large developing countries such as China is causing a rapid increase in meat consumption there, and to increasing demand for soybeans from rainforest and savannah regions elsewhere. In Brazil this process started in Mato Grosso on the southern edge of the Amazon. Massive new road building programmes are now under way in the Amazon itself, which will result in the conversion of ever-larger areas of virgin forest into soybean fields to supply the growing demand for soybean from China's cities.

Over the last 50 years agriculture in developed countries across the world has been transformed into an ever more capital intensive, machine dependent system. In the UK, only one and a half per cent of the population is still producing food. Rural landscapes here no longer exists in their own right but for the sole purpose of supplying urban demands.

Nutrient flows

Another important issue to be addressed is that, worldwide, we are seeing uni-directional food and therefore nutrient flows, from the country to the city, never to be returned to the land. This unsustainable system was pioneered in Rome 2000 years ago with the construction of the "cloaca maxima" through which much of the city's sewage was flushed into the Mediterranean. More recently, in the 1850s, London, faced with major outbreaks of typhoid and cholera due to sewage pollution of the Thames, decided to separate its people from their sewage output. After much deliberation, London's authorities took the decision not to recycle the sewage, but to dump it in the sea instead. From 1858 – the year of the "great stink" – onwards a huge investment in a sewage disposal system was made. But because most of the sewage was now flushed away rather than used as fertiliser, it became necessary to keep the farmland feeding London productive by artificial means. The age of artificial fertilisers and chemical farming had begun.

A few years ago, flying from Rio de Janeiro to Sao Paulo I observed Rio's vast, brown sewage "plume" oozing out into the sea. Similar images can be seen at coastal cities all over the world. This one-way traffic of nutrients - from farmland, via cities into the sea – is causing havoc to coastal waters across the planet. These plumes contain the nitrogen, potash and phosphate that should be used for growing the crops we eat. In addition, a substantial proportion of the artificial fertilisers now used on the world's farms also ends up polluting rivers and coastal waters. If we are to create sustainable cities, we need to look at the nutrient flows between cities and the countryside, and at the "metabolism" of our cities.

Relearning urban agriculture

Urbanisation, and the shift from rural to urban living by billions of people, has not only resulted in major environmental problems, but also in urban poverty, food insecurity, and malnutrition, particularly in developing countries. But, almost unnoticed, it has resulted in the growth of a remarkable phenomenon: urban agriculture. According to UNDP, in 1996 some 800 million people were engaged in urban agriculture worldwide, with the majority in and around Asian cities. Of these, 200 million were thought to be market producers, with 150 million people employed full time. Urban agriculture now occupies large minorities in many cities around the world. Cities such as Havana, Accra, Dar-es-Salaam and Shanghai have been studied extensively. But in thousands of other cities around the world people are also quietly getting on with their own food production.

Over the last several years I have had the opportunity to witness urban agriculture in many different parts of the world. I was interested in this because, among other things, urban agriculture can help cities make the best possible use of organic waste materials.

Urban agriculture is conducted within or on the fringe of cities. It is concerned with growing plants and herbs and raising of animals for food and other uses. The production of tree seedlings, ornamental plants and flowers is also part of the picture. It is becoming apparent that in order to survive in a globalising food system, urban farmers must be highly innovative and adaptable. They must be able cope with city constraints and tap as effectively as possible onto urban assets and resource flows. For instance, an important component is the use of compost and manures available in the urban environment.

Despite globalising tendencies, local urban food production is being practised in many places. In recent years its importance has been increasingly acknowledged by researchers, politicians and urban planners - from a largely neglected activity, to a major force for creating sustainable livelihoods for urban people.

In the developing world in particular, urban agriculture can greatly contribute to urban food security, improved nutrition, poverty alleviation and local economic development.

In developed countries its is recognised as contributing to the reduction of "food miles", involving city people in food growing and distribution via farmers' markets.

Urban agriculture often builds on ancient traditions. Historically, most cities grew out of their own hinterland, and some contemporary cities are still deeply "embedded" in their local landscapes, even in Europe. For instance, Florence is still surrounded by orange and olive groves, vineyards and wheat fields on which a large proportion of its food requirements are grown. Many cities in Italy, and also in France, still have very strong relationships to their immediate hinterland, with "peri-urban" agriculture still much in evidence.

I found the same in China. China has an age-old tradition of settlements permeated with food growing areas. Today, at a time of very rapid urban-industrial growth, urban agriculture is still a very important issue for the Chinese. Even mega-cities such as Shanghai, with about 15 per cent growth per year one of the fastest growing cities on the planet, maintains its urban farming as an important part of its economic system. A major shift has taken place, however, from "intra-urban" to "peri-urban" agriculture. As housing and office developments grew within the city, farmland there was lost and food growing shifted increasingly to the city's periphery.

The Shanghai city authorities administer an area of about 600,000 hectares of land: 300,000 of this are built up areas within the city itself. But as a deliberate policy, some 300,000 ha of land on the edge of the Shanghai are now deliberately maintained as farmland for feeding the city. Most of this land is used to supply rice and wheat, though, as we saw above, production of animal feeds such as soybeans, particularly for beef produced in US-style feedlots, now takes place increasingly in far-flung places such as the southern Amazon.

Tens of thousands of hectares on the outskirts of Shanghai are intensely cultivated with a great variety of vegetables. The Chinese like to cook fresh, locally grown vegetables. Stir-frying wilted vegetables is not regarded favourably. Glass and polythene greenhouses are now much in evidence, producing three to four successive crops a year in Shanghai's warm climate.

On the outskirts of Beijing, too, vegetable cultivation is much in evidence. But farmers have had to develop ingenious systems to cope with the much colder climate there. Greenhouses, too, are much in evidence. During frosty conditions in January and February, they cover their polythene tunnels with several layers of bamboo mats in the evening to keep the heat in at night. Few growers in and around Beijing use coal fired heating systems in their greenhouses to cope with the icy conditions outside.

In Chinese cities "closed-loop" systems, using night soil as fertilisers for urban vegetable growing are still widely maintained. The night soil is diluted, perhaps ten to one, and then ladled onto vegetable beds. I was told that people prefer vegetables grown with night soil fertiliser because they taste better. But most new apartment and office buildings, which are in evidence everywhere, have water closets, and it remains to be seen whether appropriate ways of using wastewater in urban farming can be developed.

In Russia, too, per-urban food growing is an age-old traditions, with many people retreating to their dachas at weekends to cultivate crops in highly productive gardens. In St. Petersburg most people are involved in urban farming: there are some 560,000 plots being cultivated on the periphery of the city. Even in remote places such as Irkutsk in Siberia with its very short growing season, I have seen people cultivate an amazing variety of vegetables, including cucumbers, tomatoes, in well insulated greenhouses, both for home supply as well as for sale on markets.

In South Africa, of course, during the apartheid days it was forbidden for the black majority to grow land within and around cities, because that meant people were there to stay. But now a dramatic growth of urban agriculture is under way as people get a permanent foothold in their towns and cities. And throughout Africa, in Ghana, Kenya, Tanzania and elsewhere much food growing takes place within cities, because density is still very low there and there is room for food growing. Women tend to be the cultivators in urban areas.

Havana in Cuba is a particularly remarkable example of urban agriculture development. As a result of the collapse of the Soviet Union, Cuba lost a large proportion of its sugar export earnings. So a few years ago the authorities decided to practise food import substitution and to encourage urban agriculture within the city. Composted bagasse from the sugar cane fields is often used as fertiliser. Sugar cane, ironically, is grown with artificial fertilizers, but the bagasse that is composted effectively becomes an organic fertilizer and this is used on raised vegetable's beds called "organiponicos", which are irrigated with pumped underground water. In Havana some 20,000 people now grow fruit and vegetables, mainly on plots adjoining their apartment blocks.

Whilst urban farming is being recognised more and more as an important source of food and income generation in cities around the world, adequate institutional frameworks at national, municipal and local levels are still often lacking. It is becoming important to find ways to overcome this obstacle. Rather than competing with rural agriculture, urban and rural agriculture should be seen as complementing each other since urban agriculture tends to focus on products that require closeness to the urban markets such as vegetables, flowers, poultry and eggs.
Opposition to urban agriculture has tended to come mainly from public health and urban planning circles because of concern about water pollution and soils contaminated by heavy metals. However, research has shown that concerns about adverse effects on public health have been exaggerated. There is broad consensus now that urban agriculture is an important area for government support at national as well as municipal level.

Developed countries

But, anybody who thinks that urban farming is only a phenomenon primarily of poorer countries, should have a look around parts of New York City. In the Bronx, for instance, an astonishing range of vegetable gardens has sprung up in the 1980s, primarily in areas where drug-related gang warfare resulted in houses being burnt down and gardens left abandoned. With the help of people from New York Botanical Gardens, local people turned dozens of vacant lots into thriving vegetable gardens. Many grew crops also for the sake of their children who they want to learn about growing vegetables and keeping chicken and rabbits.

In California, too, urban farming is widely practised. In the university town of Davis, some enlightened developers decided to build a "permaculture" suburb some years ago. They surrounded new eco-houses with vegetable plots and orchards. Even good quality wine is now produced right in the middle of Davis.

In the United States the growth of farmers' markets has been a remarkable phenomenon in recent years. Despite the enormous dominance of supermarkets, farmers' markets have been of extraordinary success, not only in California, where the growing conditions are best, but also in New York. There are now over 3000 farmer markets. In the UK, too, there has also been a resurgence of farmers' markets, from nothing about ten years ago to about 300 in 2002. And allotment growing has maintained its popularity within cities, though today it is less and less done by retired men, but increasingly by women who want to grow some of the vegetables for their families.

But in the UK there is also an urban food production. For instance, in Nazeing in Essex, just outside London, one can see how farming has come under pressure. Like Heathrow, Nazeing used to be a major centre for vegetable growing, in a landscape full of greenhouses. But few growers could compete with cheap, imported vegetables and many had to abandon their plots. The few that are left now grow only one crop: cucumbers. These are grown hydroponically in greenhouses that look as clean as operating theatres. The growers are mainly second generation Italians. That is because the people who used to own these greenhouses couldn't make them pay any more. The Italian prisoners of war who had been their labourers during and after the war, took over the last remaining greenhouses, partly because they could draw on additional supplies from Italy. When it isn't cost-effective to grow cucumbers in the winter in England, they will truck them in from Italy instead.

On the outskirts of Bristol, attempts have recently been made to set up new organic market garden schemes. For instance, at Leigh Court outside the city, an organic vegetable box scheme was set up in the 1990s. But it is difficult to compete with cheap, imported crops – three quarters of the organic vegetables consumed in Britain are actually trucked and flown in from elsewhere, at great energy cost. But some initial steps to revive peri-urban agriculture have now being taken.

Cities as sustainable systems

Urban agriculture is an important aspect of the wider issue of urban sustainability, both, by being able to supply food from close-by and by offering livelihoods for city people. Another important issue, as already discussed, is the efficient use of nutrients from the urban metabolism that would otherwise end up as pollutants in rivers and coastal waters.

In many cities attempts are being made to use wastewater in urban food production. This applies particularly to cities in hot and dry places. For instance, in Adelaide, Australia, tens of thousands of hectares of land on the edge of the city are cultivated using wastewater from the city for irrigation, growing vegetables as well as grapes and fruit. There is some concern about trace quantities of heavy metals that could accumulate in the soil, but it would take decades to cause any problems. Adelaide's wastewater crop irrigation system is regarded as one of the great success stories of urban agriculture.

In Bristol, Wessex Water has developed its own system for turning sewage into a soil conditioner and fertiliser. It dries the city's entire sewage output and turns it into small pellets called Biogran, which are then sold to farmers and land reclamation companies. Again, trace amounts of heavy metals have been quoted as problematic. But this is becoming less of a problem because cars no longer run on leaded fuels in the UK, and in Bristol de-industrialisation has led to a great improvement of the quality of Bristol's sewage sludge.

Another important aspect of sustainable urban development is the creation of new kinds of eco-efficient housing estates. This concept is now flourishing across Europe. In South London, a pioneering project will be completed in 2002 – the Beddington Zero Energy Development. This is a housing and workshop project for some 200 people created by the Peabody Trust and the Bioregional Development Group. All buildings have south-facing facades and 30 centimetres of insulation in walls, floor and ceilings. The apartments require only 10 per cent of conventional heating energy and this is provided by a small wood-chip fired combined heat and power plant. There are solar electric panels installed on all the south-facing facades and these will supply electricity to a small fleet of electric cars. All apartments have their own small roof gardens that can be used for recreation and/or vegetable growing. The estate's wastewater is treated in a "living machine" which uses plants and zooplankton for extracting surplus nutrients. The water from the treatment plant is used for irrigating gardens.
The Beddington project shows how ideas for making cities eco-efficient can be turned into practical reality. We need to turn the linear throughout of resources through our city, into circular systems where minimal inputs into the city result also in minimal waste outputs. Energy efficiency, resource productivity - these are the key themes in this context. But it is of crucial importance also to bring the food supply - at least some of the food consumed in our cities - close to the edge of the city's, and into the city itself.

Good urban design in the 21st century should start by mimicking natural eco-systems. Above all else, we would be well served to learn from the metabolism of natural, closed-loop systems in which all wastes are recycled into resources for future growth. This is an issue for policymakers, but also for the general public which needs to exert pressure on local and central governments and on developers to adopt forward looking practises.

We're certainly seeing a lot of interest in these ideas now in cities all over the world. But a major push is still needed to reduce the wasteful resource consumption and the vast, sprawling ecological footprints of cities that we have at present. We need to move towards much more localised, much more efficient, much more circular urban systems, and this scenario certainly includes the use of land within and on the edge of cities for food production. Ideas for creating sustainable cities have been around for some time, but implementation on an adequate scale has hardly begun.

Hard and soft science issues to be negotiated to improve urban metabolism

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Introduction

In the industrialised world, waste management systems have developed to maturity without primary concern for recycling. These systems have originally been designed to ensure human health and a high local hygienic standard. More recently environmental concerns have been the driving force behind a technological development of sewage treatment with biological removal of N, P, and organic matter. This technology addresses some immediate problems in the aquatic environment, but the sewage sludge from the treatment plants contains considerable quantities of xenobiotic compounds and heavy metals, and only a fraction of the nutrients that entered the urban areas, thus making the sludge a non-attractive fertiliser source. In recent years there has been concern about the sustainability of this state of affairs as regards wastewater handling, as well as concern about the fate of the final waste deposits in the environment. In the mid 1990s Danish organic farmers made a point of refusing to accept sewage sludge as a source of nutrients. This sparked a heated debate, and for a time all farmer organisations refused to accept sewage sludge on their fields, leading to severe problems in urban areas. One of the consequences of this conflict is that municipalities are increasingly seeking alternatives to returning sewage sludge to the land (e.g. burning or dumping), in order to rid their dependence of farmers' acceptance.

Another consequence has been that the issue of 'closing the urban-rural nutrient circle' as part of a sustainable development has received increasing attention among Danish organic farmers. This issue had been identified already in the early days of the organic movement in Denmark, but has never been a top priority. It was accentuated by a strong Swedish emphasis of agricultural use of human urine from source separating toilets that provided inspiration to look at implementing such techniques in Danish urban areas.

One additional factor that has increased the priorities of the issue was the growing realisation that current day organic farmers have a strong bias towards milk production, due to the natural integration of the clover-grass in the production system, that is essential for ensuring an ample supply of fixed atmospheric nitrogen. If more stockless organic farms (e.g. vegetable and grain production for human consumption) are to become economically sustainable, it is important to find ways of using the land with less emphasis on clover grass. One of the ways of doing this is to increase the amounts of nutrients that can be re-cycled from urban areas in a form that is acceptable to organic farms.

Box 1 The NUTRAP centre

Central to the strategy for working towards closing the urban-rural nutrient cycle has been the formation of

NUTRAP

CENTRE FOR APPROPRIATE TECHNOLOGIES FOR NUTRIENT RECYCLING FROM HUMAN WASTE TO AGRICULTURE IN PERI-URBAN AREAS

At present the following institutions have signed a memorandum of understanding to this end:

The Departments for Agricultural Sciences and Veterinary Microbiology, KVL
The Department for Environment and Resources, DTU, and
The National Environmental Research Institute (DMU)

Link to: www.agsci.kvl.dk/nutrap

Identification of urban fertiliser potentials

Recycling from the food and other bio-processing industry waste has been estimated to be approximately 99% in Denmark (Danish EPA, 1998) since waste from this sector is either used for fodder or fertiliser directly or after bio-gas production. Based on this assessment it was decided that there was little need to include industrial wastes in the view of improving re-circulation.

However, the waste management in urban households, service sector, and other industries poses a separate challenge. State-of-the-art systems are based on collection of solid waste (often separated in an organic and non-organic fraction) and treatment of waste-water. The sewage systems receive black water (physiological fraction), grey-water (washing and cleaning), and storm water runoff. The composition of waste sources from households in Scandinavia (table 1) clearly indicates that the urine and faeces fraction contains by far most of the nutrients in the household waste. Thus night soil together with the solid organic household waste theoretically constitutes app. 1% of total household waste volume, but contains 82-87% of the nutrients. By removing this nutrient rich household waste the need for nutrient removal from sewage would be minimal or non-existant (see figure 1).

Table 1 The composition of waste sources from households in Scandinavia (grams per person per day) and their relative contribution to weight and nutrient content. Modified from Magid et al. (1999)

	Total	Physiological Faeces	Physiological Urine	Kitchen Liquid	Solid	Bathroom Grey water
Dry matter	235	35	60	40	80	20
Chemical oxygen demand	220	60	15	45	90	10
Biological oxygen demand	90	20	5	30	30	5
Nitrogen	15.7	1	11	1	1,7	1
Phosphorus	2.8	0,5	1.5	0.2	0.3	0.3
Potassium	4.7	1	2.5	0.4	0.4	0.4
Contribution to waste weight (%)		0.1	0.8	7	0.3	91.7
Contribution to N in waste (%)		6	70	6	11	6
Contribution to P in waste (%)		18	54	7	11	11
Contribution to K in waste (%)		21	53	9	9	9

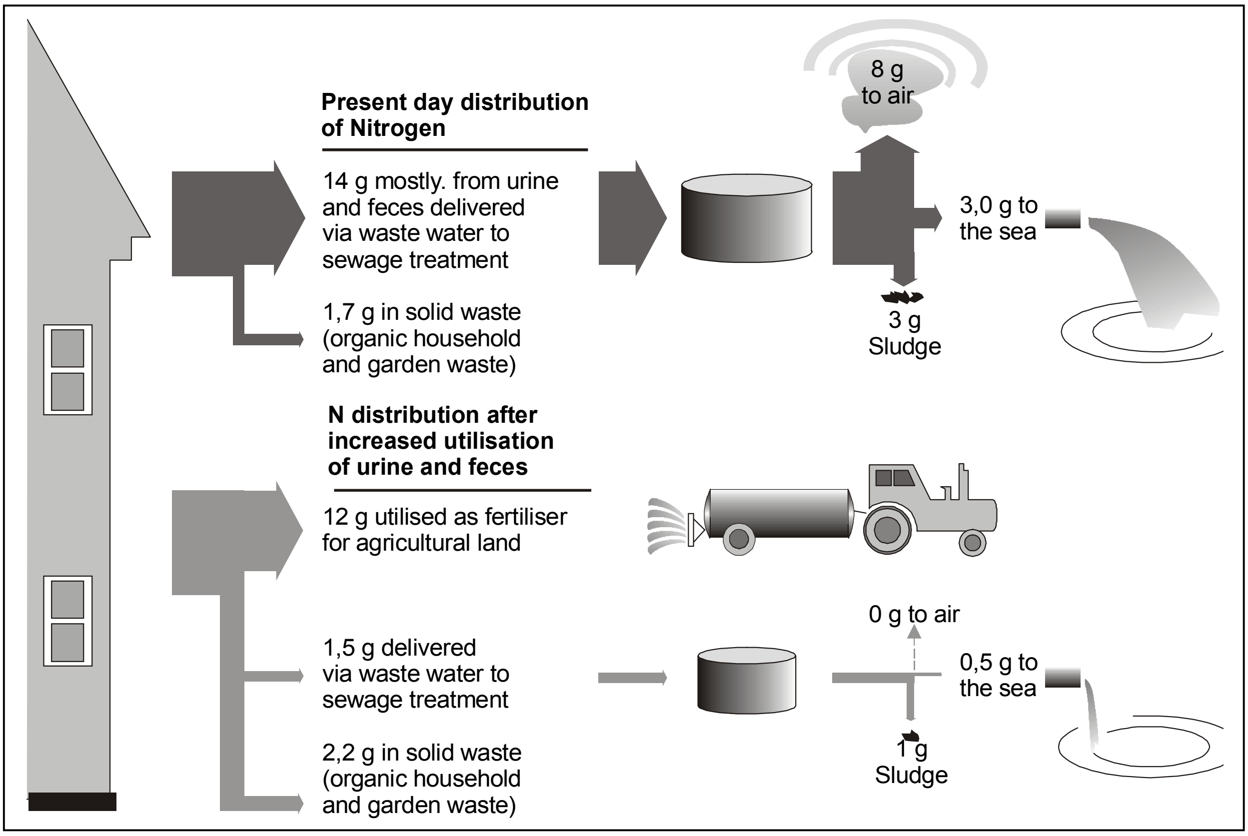


Figure 1 Conceptual diagram of Nitrogen distribution from households (per person per day) in present day and future sanitation systems (delivered by Eilersen and Henze, IMT, Danish Technical University)

In practice, systems need to be developed in order to manage this nutrient rich household waste from urban areas, but a realistic estimate based on minimal flushing systems indicates the volume of this nutrient rich waste to be no more than 2-3 m^3 $person^{-1}$ yr^{-1}, as the volume of urine (450 l), faeces (60 l), and organic household waste (150 l) in itself will be less than 0.7 m^3 $person^{-1}$ yr^{-1}. In Scandinavia such systems have been developed and tested for rural areas without sewage systems, and currently trials with such systems are being made in urban areas.

Waste streams in urban areas can be handled in a number of different ways, giving rise to different products. In table 2 an overview of the findings on present day and future urban fertilisers is given.

Nutrient recycling is not the only consideration with respect to waste handling. It is important to look at the total waste generation as well as at the total waste handling system, and attempt to reach an overall optimal system. Recycling nutrients in itself probably does not balance the costs of implementing changes in waste management, if handling of other waste streams gives growing problems.

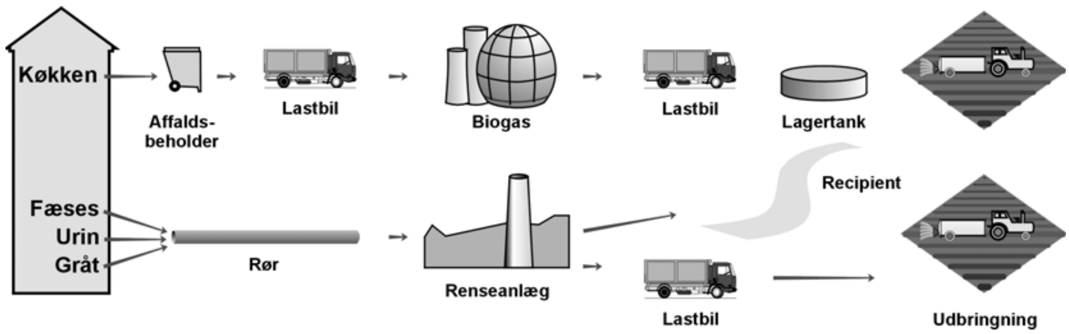
The maximum amount that can be recycled from the urban areas would cover no more than 5% of the current day nutrient input to agriculture (Magid et al., 1998), although in certain parts of the country (metropolitan areas) most of the agricultural nutrient demand could be supplied from urban areas. While the figure of 5% may seem low it should be seen in the context that Danish agriculture is highly intensive, based on imports of feed and fertilisers that are necessary to ensure the present production levels of meat and milk products for exports and, therefore, the off-take of our urban population appears small. It can be discussed if this general state of affairs in Danish agriculture is sustainable in the long-term. It is, however, undeniable that recovering 5% of the current day agricultural nutrient flow could sustain a considerable food production for local consumption.

Table 2 Overview of the findings on present day and future urban fertilisers (based on Magid et al. 1998)

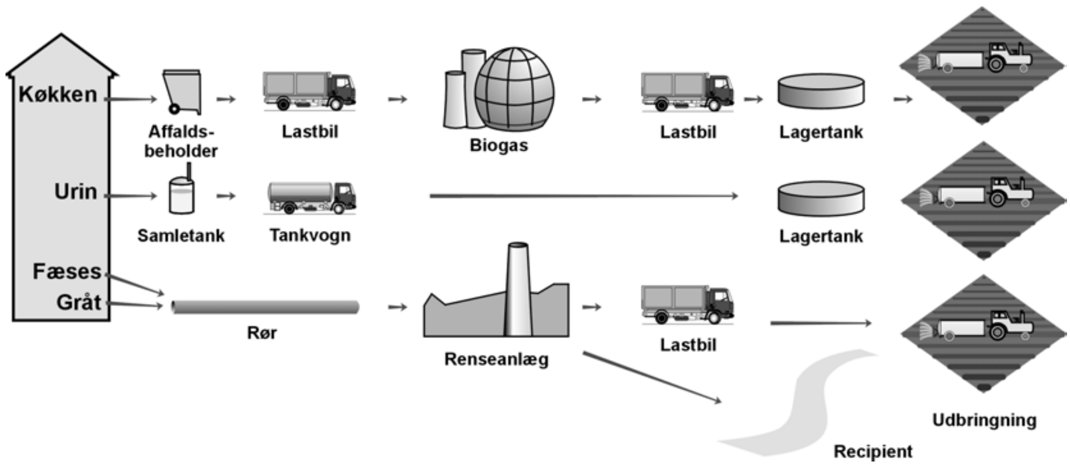
	Product	Comment
Cities of today	Sewage sludge	Rich in P, but poor in most other nutrients, notably N, K, S, and some of the micro-nutrients. Considered a dubious fertiliser because it is very unbalanced and contains unknown quantities of xenobiotics. Problems with heavy metals may occur in the longer term. Hygienic risks have been considered in the currently implemented law on agricultural use of waste products.
	Composted household waste	There have been problems with too high contents of heavy metals (mostly solved). Little hygienic risk beyond the initial pre-composting handling. If the compost is dominated by garden waste it may work better as a soil conditioner than as a fertiliser. Hygienic risks have been considered in the currently implemented law on agricultural use of waste products.
	Ashes from bio-fuel heat and electricity plants	Rich in K and S and some micro-nutrients. In the combustion plant a sorting of the ashes takes place. Some of these should be avoided, since they contain high amounts of heavy metals
Cities in the future	Sewage sludge	See above. Will be present in the cities for many years to come, due to the high investment in the present day infrastructure. May become less problematic, if xenobiotics become increasingly phased out of the matter streams
	Human urine	Well-balanced nutrient source. With appropriate storage it does not impose hygienic risks to handlers, nor to consumers of fertilised product, according to Swedish health authorities.
	Composted faeces/household waste mixture	See above. Introducing human faeces may increase risks during handling, whereas risks afterwards are unknown
	Degassed faeces/household waste mixture	Have not been successfully implemented in Denmark either with or without human faeces. Health risks are not well known, but considered acceptable based on general knowledge. Current installations are mainly fed with animal manure, fat containing industrial wastes, and/or sewage sludge.
	Ashes from bio-fuel heat and electricity plants	See above

Assessment of possibilities and barriers for recycling of nutrients from urban areas to peri-urban agriculture

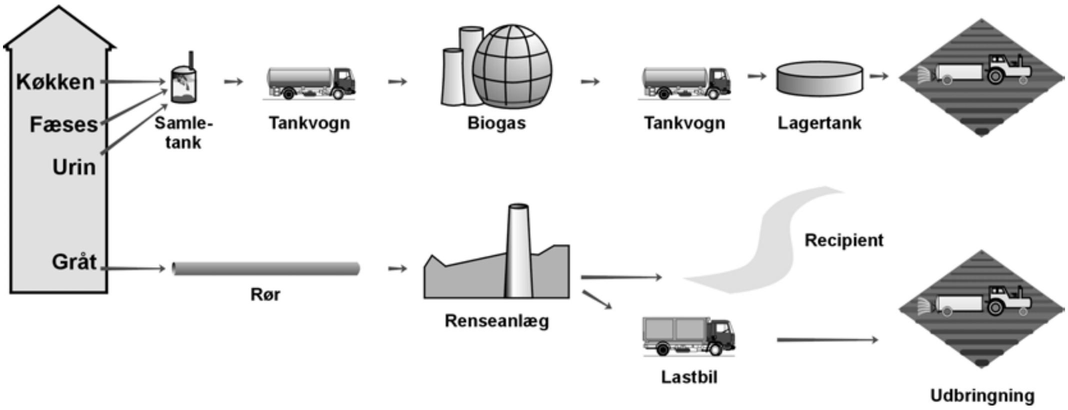
In a recent project, 14 handling systems for domestic wastewater and organic kitchen waste have been described and evaluated (Wrisberg et al., 2001). A method for choosing systems for different housing areas in a city was developed. The method was used for the city of Hillerød with 26,000 inhabitants, where four handling systems where chosen. These systems are graphically illustrated in figure 2 below. There are several advantages from using the four systems instead of the already existing sewer system. The energy surplus was the same as the energy consumption for 900 households, the nutrients collected within the systems were enough to fertilise 451 hectares of agricultural land. The yearly costs were estimated to be 17% higher than in the existing system.



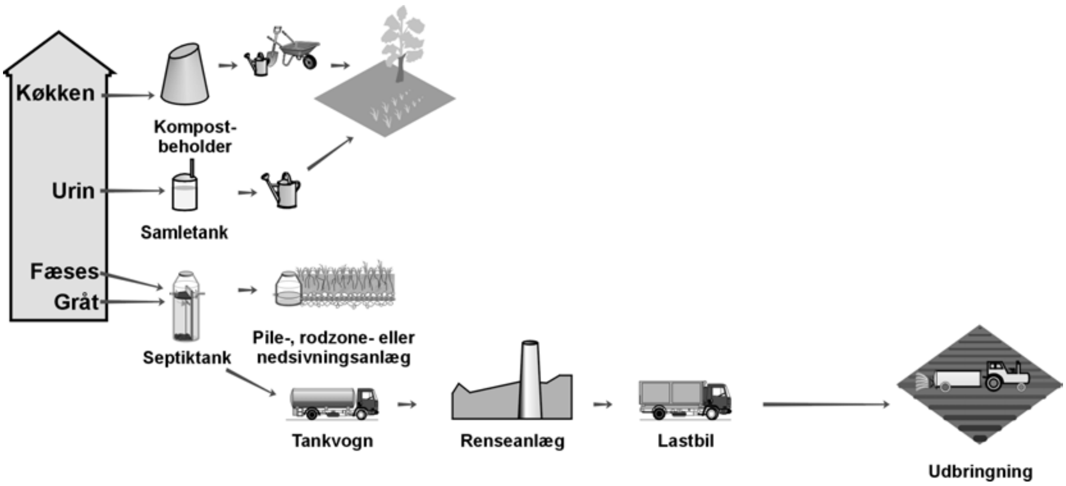
System 1: Kitchen waste is treated in a biogas plant. Urine faeces and grey water are treated in a wastewater plant.



System 2: Kitchen waste is treated in a biogas plant. Urine is collected separately, faeces and grey water are treated on a wastewater plant.



System 3: Kitchen, faeces and urine are treated in a biogas plant, grey water is treated on a wastewater plant



System 4: Kitchen waste and faeces are composted. Urine is collected while grey water is infiltrated into soil.

The pertinent scientific issues

Based on the work we have done so far, we have identified a number of wider issues that need to be addressed by research in the future:

a) Housing forms allowing recycling
b) Technologies for waste and water stream management
c) Health and hygienic risks
d) Ecosystem integrity and soil health
e) Environmental risks
f) Agronomic potential of urban fertilisers
g) Cultural acceptability
h) Economic viability

In the section below some background knowledge for a few of the identified issues is discussed in some detail, with a view to presenting a qualified approach for dealing with the problems.

Perceived threats to the environment and to the ecosystem integrity

The most imminent threat to the environment and the ecosystem integrity is related to transfer of disease vectors from urban fertilisers to animals or humans. However, since the 'Urban metabolism' is far from understood and not really under control, it is not possible to foresee which unintended effects the use of urban fertilisers may have on soil quality and the surrounding environment. This is a further justification for developing a long-term trial (see Box 2), in order to ensure that any such effects can be observed in time to prevent problems in the a context. Unknown quantities of unknown organic xenobiotic compounds may occur in sewage sludge. Similarly, human urine will contain quantities of medicinal substances that have been secreted from the kidneys, as well as chemicals from whatever detergent that has been used for cleaning the toilet. Heavy metals are a part and parcel of modern life, e.g. copper tubes in buildings, zinc on roofs, and many other surfaces as well as in cosmetics and shampoo. Thus in sewage sludge the heavy metals cannot be avoided in concentrations above what would be expected if the only contributing factor was the content in food delivered from agriculture. Even in human urine it is conceivable that contamination from tubes and storage tanks may occur. There is little available knowledge on long-term effects of various xenobiotics. However, in recent years a considerable body of knowledge has been gained on the effect of moderate increases in heavy metal concentrations in soil on some key biological processes.

Generally, heavy metals in soils are only plant available to a very limited extent, due to their reactivity within the soil matrix. Many of these are described as micro-nutrients (e.g. Cu and Zn), since they are only taken up in very small quantities and are essential for the completion of the plant life cycle. Therefore, only few observations of damages to plants or to animals and humans through the transmission of heavy metals in the food chain via plants have been reported. On Woburn Experimental Farm, the Market Garden Experiment was established in 1942, at a time when the supply of industrial nitrate was strictly limited to use for ammunition, due to the ongoing war. Among the treatments examined was heavy metal contaminated sludge from London's sewage works. These experiments were terminated after 20 years at which time the heavy metal concentration had increased substantially in a number of treatments. These plots were used afterwards to study the uptake of heavy metals in various crops, and virtually no ill effects were observed, except in red beet, which is especially sensitive to certain heavy metals (McGrath, 1987).

Therefore, it came as a surprise when clover sown in the sludge treatments was sickly and yellow, while clover growing on uncontaminated plots was healthy and dark green (McGrath, 1994). Closer inspection of the diseased clover revealed that the roots had not formed normal pink nodules that legumes usually form with nitrogen fixing bacteria. These observations could be repeated in the laboratory, while poor growth of clover could be alleviated by addition of inorganic nitrogen. Use of ^{15}N clearly indicated that clover growing in contaminated soils had lost its N-fixing capability (McGrath et al., 1988). Furthermore, plants growing in the contaminated soils failed to form VA-mychorrhizal associations. These results have been corroborated by independent observations from sludge treated soils from Braunschweig and has led to a comprehensive European effort to understand the causes for these very considerable reductions in soil quality. One of the crucial issues in this regard has to do with the very long-term impact of heavy metal accumulations in soil, since they are not 'biodegradable'. Thus, according to Witter (1996), it will take anything from a few thousand years up to 180,000 years for soils to decontaminate naturally, once they have been loaded with a certain (moderate) amount of heavy metals.

One of the most important lessons from the work on heavy metal impact on key biological soil functions was the realisation that addition of heavy metals to soil did not result in acute toxicity, and only prolonged exposure (18 months) provided effects comparable to those observed in the field trials (Chaudri et al., 1993). It is currently believed that the delayed response of nitrogen fixing bacteria to heavy metal pollution is caused by the transfer of plasmids from resistant Rhizobia to non-resistant forms, and that the transfer of this plasmid results in a deactivation of the bacterial nitrogen fixing capacity, while at the same time it delivers heavy metal resistance (Ken Giller, personal communication). This work, like no other, demonstrates the need for long-term field experiments for proper evaluation of unintended effects on soil quality and ecosystem integrity.

The way forward

Changes in soil quality occur gradually and will often not be measurable until the soil has been treated systematically over a number of years. Therefore, the long-term trials with urban fertilisers must be undertaken in order to assess such effects. We have successfully developed a proposal (see Box 2) for a research project on the use of urban fertilisers.

Box. 2 A brief description of the CRUCIAL project, which has been financed to run from August 2001 until August 2006

CRUCIAL

Closing the Rural-Urban Nutrient Cycle

WP	Work Package	Responsible
1	Establishment and running of long-term field trials with urban fertiliser	Jakob Magid, Royal Veterinary and Agricultural University
2	Developing composting practices for household waste and human faeces	Jakob Møller, Danish Forest and Landscape Research Institute
3	Carbon and nitrogen dynamics associated with use of urban fertilisers	Jakob Magid, Royal Veterinary and Agricultural University
4	P turnover in soils ammended with urban fertilisers	Bent Christensen Danish Institute of Agricultural Sciences
5	Monitoring soil quality	Poul Henning Krogh, National Environmental Research Institute

a) Dept. Agricultural Sciences has commited itself to run the experiment over a long-term period (>15 yr)

It is expected that the CRUCIAL project will provide opportunities for addressing a number of the issues identified above, i.e. "health and hygienic risks", "ecosystem integrity and soil health", "environmental risks", “agronomic potential of urban fertilisers", and in part "cultural acceptability" as well as “economic viability".

However, the work that will be carried out in connection with the coming CRUCIAL project will mainly be able to tackle biological and environmental issues, and only to the extent that a wider public interest is generated by this work it will be able to touch upon the socio-cultural issues.

Thus we face the problem of finding a way in which to integrate the divers issues within research that have been identified above as being essential to improve the urban metabolism. Given that we are still in a developmental stage, in which integrated waste management solutions have not been fully tested and proven in terms of technical, biological, and cultural measures of acceptability, the appropriate units for testing and developing solutions should not be very large.

It would be very relevant to develop co-operation with existing or planned smaller housing areas (50-150 persons) in which there is an interest in making such systems work that takes care of all the waste in an integrated way. This would provide a testing ground that would allow a realistic assessment of a large number of technical, biological, and cultural issues, and the supply of urban fertilisers would be sufficient for an experimental farm. At a later stage, the expansion of such solutions to larger urban enclaves (2,000-10,000 persons) would allow a recycling of nutrients and organic matter on a scale that would be economically interesting both for the farmers involved and for the society as a whole.

Sectoralisation and specialisation within disciplines

Apart from the issue of funding, it is clear that one of the major challenges rests with the division of competence among ministries and sectors of society responsible for agriculture, housing, health, and environment. This is also reflected in the sciences that are required to contribute to a solution – there are not many examples of R&D projects integrating technical, biological, and socio-cultural sciences.

In order to bridge the gaps between ministries and sectors it is probably necessary to involve the politicians, since the bureaucracies tend to avoid taking responsibility for complex issues. In order to bridge the gaps between the sciences, it is necessary to choose appropriate study areas (housing areas) and go outside the laboratories and offices and start working together.

This process will be dependent on a complex interplay between scientists, grass roots, bureaucrats and politicians. It remains to be seen if the development of improved urban solutions will be successful – we will do our best to make it happen.

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Urine separation - Swedish experiences

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Abstract

Urine is the urban waste fraction containing the largest amounts of nutrients. It contains approximately 70% of the nitrogen and 50% of the phosphorous and potassium in all household waste and wastewater fractions. During the 1990s, urine separation has been thoroughly investigated in several research projects in Sweden. In these measurements between 50% and 85% of the urine has been source separated, depending on the motivation and dedication of the inhabitants.

The initial problems connected with the system, mainly stoppages in the toilet u-bend, have now largely been overcome and now the system functions without any large problems.

The urine is sanitised by enclosed storage and recommendations have been developed. The storage period recommended depends on which crops that are to be fertilised, storage conditions, and type of system.

The fertilising effect of urine to cereals has for nitrogen been found to be close to that of chemical fertiliser (~90%) and for phosphorous to be equal to that of chemical fertiliser. The measured ammonia emissions after fertilisation to cereal crops have been 5%±5%. If the system is correctly designed, the ammonia emissions from collection, transport and storage are insignificant (<1%).

The environmental effects of urine separation have been investigated in several studies. They have all concluded that compared to a conventional sewage system, urine separation will recycle much more plant nutrients, especially nitrogen, and will have lower water emissions of nutrients. Generally, urine separation has also been found to save energy. Urine separation has in all studies been found preferable to the conventional system from an environmental point of view.

Urine separation is now well documented and can be recommended for implementation under most conditions.

Introduction

Urine is the urban waste fraction containing the largest amounts of nutrients. It contains approximately 70% of the nitrogen and 50% of the phosphorous and potassium in all household waste and wastewater fractions, while the flow of urine is comparatively small (figure 1).

This means that it is interesting to separate the urine at the source, i.e. the toilet. The urine separating toilets that were re-invented in Sweden in the 1980s, made the construction of urine separating systems possible. In these, the urine is source separated. The urine is then piped to collection tanks, stored and used as a fertiliser for agricultural and horticultural crops.

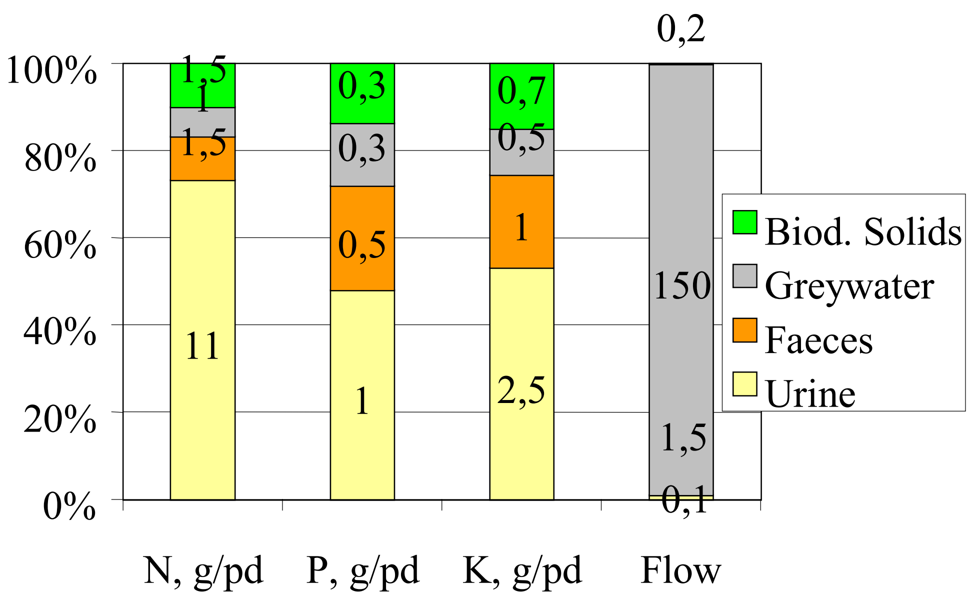

Figure 1 Distribution of nutrient flows, in grams per person and day (g/pd), and mass flow, in kg per person and day, of household waste and wastewater in Sweden (SEPA, 1995; Sonesson & Jönsson, 1996; Kärrman et al., 1999).

Research in Sweden

Urine separation received much interest from researchers in Sweden during the 1990s. There were three important research groups. The largest group was centred in the Uppsala-Stockholm region and consisted of researchers from SLU (Swedish University of Agricultural Sciences), SMI (Swedish Institute for Infectious Disease Control), JTI (Swedish Institute for Agricultural and Environmental Engineering), and KTH (Royal Institute of Technology). Below are listed the research centres, which aspects they have mainly been studying, and the names of the most active researchers.

- SLU, SMI, JTI, KTH
  - Hygiene, function, i.e. degree of separation, functional problems, fertilising effects, resource usage, emissions, developing countries
  - *At SLU; H. Jönsson, B. Vinnerås, at SMI; C. Schönning (prev. Höglund), T.A. Stenström and at JTI A. Richert Stintzing*
- Luleå Technical University
  - Exergy analysis, storage, drying, nitrification
  - *D. Hellström, E. Johansson, J. Hanaeus*
- Gothenburg University
  - Algae growth, conc. (struvite, ion ex, freezing, etc)
  - *M. Adamsson, B.B. Lind, Z. Ban, S. Bydén*

In addition to these groups, some individual researchers in other places have been active.

To finance this research, the housing and agricultural sectors have made the largest contributions. The water and wastewater sector has also made a large contribution, while the contributions by other sectors of society, for example the environmental sector, have been small. The most important financing bodies have been: BFR (Swedish Council for Building Research), SLF (Swedish Farmers Foundation for Agricultural Research), VA-FORSK (Swedish Municipalities Sewage Research Program), Swedish Board of Agriculture, Stockholm Water Inc., National Cooperation of HSB, and Stockholmshem Inc.

Results

The results presented below are mainly based on the research done by the group centred around SLU and SMI. The results presented below are presented in more detail by Jönsson et al. (2000), Höglund (2001), Jönsson et al. (1997), Jönsson et al. (1999) and Johansson et. al. (2001), Lindgren (1999) & Vinnerås (2001).

Hygiene

The hygienic research carried out is described by Caroline Schönning in another paper at this seminar, therefore the results are here given extremely short. Pathogens were found to die off during storage and recommendations have been developed for how the urine should be sanitised via storage before being used as a fertiliser. The storage period recommended depends on which crops that are to be fertilised, storage conditions, and type of system (small or large system).

Toilet - function and degree of separation

The function of the toilet and the degree of separation have been studied in measurements in five different housing districts with altogether 315 inhabitants (table 1). Most of the measurements have lasted around 30 consecutive days. The apartments in most of the districts were rented, but the eco-village, Understenshöjden, was tenant owned. The inhabitants in Understenshöjden had decided themselves that they wanted a urine separating sewage system in the eco-village. In the other districts, the house owner had installed urine separation without asking the tenants. Thus, the inhabitants of Understenshöjden were much more informed, motivated, and dedicated than the inhabitants in the other districts. The tenants in Miljöhuset, on they other hand, knew very little about urine separation and why they had urine separating toilets. One reason for this is that they moved much more frequently, on average, than people in the other houses. As is seen in table 1, the motivation and dedication by the inhabitants have a profound impact on the percentage of urine actually being source separated.

Table 1 Investigated housing districts and the calculated percentage of source separated nutrients in each district. In some measurements some phosphorous or nitrogen was probably lost in the collection and handling of the samples. Thus, these numbers are minimum figures and in the table they are given in italics

	Understens-höjden	**Palster nackan**	**Hus-hagen**	**Eko-porten**	**Miljöhuset**
Inhabitants	160	50	8	35	62
Toilet	BB Dn	BB Dn	WM DS	BB Dn	BB Dn
Apartment type	Tenant owned eco-village	Rented	Rented	Rented	Rented
Urine-N collected, %	78	59	65	*>62*	46
Urine-P collected, %	74	61	*>65*	62	*>40*
Urine-K collected, %	95	70	58	87	49

Toilet – function and degree of separation

The function of the toilets were studied in two questionnaires, one in 1997 to 96 households and one following up in 1999 to 73 households. The two toilets studied were Dubbletten and DS. The most important problem found was that stoppages normally appeared in the u-bend of the toilet after a short time. These stoppages were a big problem, since the users did not know how to clear them. Studies of the stoppages showed that 76% of them mainly consisted of precipitation, mainly calcium and magnesium ammonium phosphates, forming on hairs and fibres. These stoppages could easily be cleared with a mechanical snake or with caustic soda. The remaining 24% of the stoppages consisted of precipitation on the pipe wall, which could efficiently be cleared with caustic soda. From talking to users, now that they know how to clear the stoppages, they say that the stoppages are not a problem any more. Like stoppages in the u-bend of the shower, they appear once or a few times a year and are easy to clear.

Some users also complained about inadequate flushing of the urine bowl and of odours. However, these problems were small, and the toilet manufacturers have been trying to deal with them, so they might not exist on new installations.

The following recommendations were derived from the studies:

- The flow from the urine bowl should not be hindered by anything (hairs and fibres should be flushed away by the water when cleaning the toilet).
- It should be possible to use a mechanical snake to clear the urine u-bend.
- The urine u-bend should be easy to access and disassemble (which probably will not be needed, but just in case).
- The urine bowl should suit also men urinating while standing up, otherwise the percentage of urine actually separated will drop.
- The toilet should be comfortable and easy to use (try it before purchase)

- The flush of the urine bowl should be effective and use little water (≤0.1 l/urination).
- The toilet or system should contain no metal in contact with the urine mixture.
- The toilet should be easy to clean.

Pipes and tanks

Measurements and observations by video and naked eye of pipes and tanks have resulted in the following results and recommendations:

- Installations must be water tight (pipes should be welded or similar). Ground water leaking in was the most frequent problem found!
- Horizontal pipes should have a slope of at least 1% and a diameter of ≥75 mm (preferably 110 mm), because sludge continuously precipitates from the urine mixture. The sludge is easy to flush away.
- The pipes should have good opportunities for inspection and cleaning.
- The system should not be ventilated. If it is correctly constructed the total ammonia emission from collection, transport, and storage is <1%.
- The tanks should be filled from the bottom and have the man hole close to the incoming pipe.

Fertilising effect

The fertilising effect of source separated urine has been investigated in two pot experiments, a three-year field experiment and a one-year field demonstration.

Source separated human urine is a well balanced complete fertiliser and its nutrients are readily available to plants. The nitrogen effect was found to be close to that of chemical fertiliser (~90%). It varied between 70% and more than 100% between different years. The phosphorous effect was equal to that of chemical fertiliser.

In the experiments, the ammonia emission after spreading varied between less than 1% and 10%. It averaged around 5%. No toxic effects have been observed in these or other experiments with cereals. The urine has been spread on the soil or in the growing crop. However, the nitrogen in stored urine is mainly found as ammonia and it is well known that some crops easily burn if ammonia is applied on the plants themselves.

The concentrations of heavy metals in source separated urine are very low. For example the Cd/P ratio was around 2 mg Cd per kg of P. In spite of this, the European Union (EU) only allows the use of source separated urine in conventional farming, not in organic farming. It is very important that in the future urine will also be allowed in organic farming.

Emissions and resource usage

The computer package ORWARE was used to model and simulate the urine separating sewage system of Palsternackan, where the faecal water (faeces, paper, and flush water) and greywater were treated in the central sewage treatment plant in Stockholm. The calculated environmental effects and resource usage of this system were compared to those calculated for a conventional sewage system, using conventional toilets and treating all wastewater, including the urine, in the central treatment plant. In both systems, 50% of the generated sewage sludge was assumed to be spread on arable land and 50% was assumed to be landfilled.

Urine separation decreased the emissions of nitrogen and phosphorus to water by 55% and 33%, respectively. A large fraction of the plant nutrients were recycled, instead of being led to the treatment plant. Thus, the urine separating system, compared to the conventional system, recycled 27 times more plant available nitrogen, 35% more phosphorus and 25 times more potassium.
The levels of heavy metals were very low in the urine. Mercury, cadmium, and lead were all below their detection limits, 0.0004, 0.0013, and 0.027 mg/l, respectively. These values corresponded to: <1 mg Hg/kg P, <4 mg Cd/kg P, and <89 mg Pb/kg P. In the measurements at Ekoporten, performed after this ORWARE study, the detection limit for cadmium was lowered and it was found that the Cd/P ratio was 2 mg Cd/kg P. Thus, urine is a very clean fertiliser.

Energy, 24 MJ/person and year, was required for transporting the urine mixture 33 km with a truck and trailer to a farm and for spreading it as a fertiliser. However, the decreased nutrient load on the sewage system meant that 31 MJ/person and year were saved in the sewage system. In addition, the source separated urine replaced mineral fertilisers, which would have required 75 MJ/person and year to produce. Thus, urine separation saved in total 82 MJ/person and year. A sensitivity analysis showed that the urine mixture could be transported 220 km by truck and trailer before the urine separating system used as much energy as the conventional one.

Urine separation has also been investigated in a number of other environmental systems analyses using the methods life cycle assessment and mass flow analysis. These studies have been using a variety of data and assumptions. Considering the environmental impacts and the use of natural resources, they have all concluded that urine separation is preferable to the conventional sewage system (Bengtsson et al., 1997; Bjuggren et. al., 1998; Kärrman et. al, 1999; Kärrman & Jönsson, 2001; Jernlid & Karlsson, 1997; Tidåker & Jönsson, 2001; Tillman et al., 1997). Therefore, the conclusion that the sewage system is improved if it is supplemented with urine separation seems robust. It seems to hold under most conditions and assumptions. Urine separation improves the sewage system more, when the reduction achieved in the sewage treatment is low.

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Hygienic aspects on the reuse of source-separated human urine

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Introduction

Human excreta contain plant nutrients and have traditionally been used for crop fertilisation in many countries. In Japan the recycling of urine and faeces was introduced in the 12th century and in China human and animal excreta have been composted for thousands of years. Urine is the fraction that contains the major part of the nutrients in domestic wastewater, approximately 80% of the nitrogen, 55% of the phosphorous, and 60% of the potassium (Swedish EPA, 1995). At the same time it constitutes less than 1% of the total wastewater volume. Thus it is possible to collect a relatively concentrated fertiliser by separating urine from the wastewater. Faeces contributes a smaller amount of nutrients and involves greater health risks, if reused, due to the possible presence of enteric pathogens. Human urine does not generally contain pathogens that can be transmitted through the environment.

The handling and reuse of all different types of waste products with human or animal origins involve hygiene risks. Whether human excreta (faeces and/or urine) are reused directly, diluted in wastewater (treated or untreated) that is reused, or are a constituent of sewage sludge used in agriculture, enteric pathogens will be present and able to cause infections by ingestion of the waste product or by consumption of crops that have been fertilised. Cysts and oocysts of protozoa and helminth ova are considered to be of great public health concern since they remain viable for extended periods outside their human host (Cooper and Olivieri, 1998), and viruses have received attention due to low infectious doses and difficulties in analysing their presence in waste products (Asano and Levine, 1998).

Many of the ecological sanitation alternatives being introduced are small-scale systems that demand more personal involvement of the users, including handling of the waste. Thus if not sufficiently treated the possible exposure points for pathogens are increasing compared to conventional piped systems. With the main goals of recycling nutrients and minimising utilisation of natural resources, hygiene aspects must be prioritised. To successfully introduce and optimise alternative wastewater systems it is necessary to evaluate hygiene risks and sanitary aspects in accordance with sustainability criteria. Thereafter, recommendations for e.g. storage, treatment, or reuse practices should be formulated.

Microorganisms in urine

In a healthy individual the urine is sterile in the bladder. When transported out of the body different types of dermal bacteria are picked up and freshly excreted urine normally contains <10 000 bacteria per ml (Tortora *et al.*, 1992). Urinary tract infections result in significantly higher amounts of excreted bacteria. These have not been reported to be transmitted to other individuals through the environment. The pathogens traditionally known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi,* and *Schistosoma haematobium* (Feachem *et al.*, 1983). These are rarely sufficiently common in urine to constitute a significant public health problem and are thus not considered to constitute a health risk related to the reuse of human urine in temperate climates. An exception in tropical areas is *Schistosoma haematobium*, which however implies a low risk due to its lifecycle where a freshwater snail is needed as an intermediate host. Furthermore, the inactivation of urinary excreted pathogens in the environment reduces their ability for transmission.

Aim of the study

Source-separation of urine and faeces is possible by using urine-separating (or urine-diverting) toilets, available as simple dry toilets or porcelain flush toilets with divided bowls. The aim of this study was to investigate and evaluate health risks from infectious diseases related to handling and reuse of source-separated urine in agriculture.

The specific objectives were:

- to determine the faecal contamination that occurs in urine-separating toilets;
- to determine the inactivation rates of different groups of microorganisms in source-separated human urine and relate the inactivation to some of the characteristics of the urine mixture (urine + flushwater);
- to quantify microbial health risks in urine-separating sanitation systems by using Quantitative Microbial Risk Assessment (QMRA).

Faecal contamination

Faeces does not always contain pathogens. However, from a risk perspective its presence should always be considered since there are so many different types of enteric infections and the prevalence is unknown for several of them. Any faecal cross-contamination that may occur by misplacement of faeces in the urine-separating toilet is therefore regarded as a possible health risk. To estimate the risk of pathogen transmission during handling, transportation, and reuse of source-separated urine, the amount of faecal material contaminating the urine fraction was determined by analysing various indicators in the urine mixture, i.e. the collected urine and flushwater.

Analysis of faecal indicator bacteria

Analyses of various indicator bacteria implied different degrees of faecal contamination if evaluated according to their normal abundance in faeces, which in further investigations could partly be explained by different growth and survival characteristics. *E. coli* had a rapid inactivation in the urine, and faecal streptococci were found to grow within the urine pipes. It was concluded that none of the commonly used indicator bacteria were suitable to quantify faecal cross-contamination in source-separated urine.

Analysis of faecal sterols

As an alternative or complement to microorganisms in detecting faecal contamination, chemical biomarkers have been suggested as indicators. The most widely studied biomarkers are probably coprostanol and structurally related faecal sterols (Vivian, 1986). These compounds are metabolites of cholesterol formed in the intestine and excreted in faeces. One advantage compared to bacterial analysis is that samples can be analysed after some time of storage. However, rather sophisticated and complex equipment is needed.

The presence of human faeces in urine samples was successfully determined by analysing for faecal sterols. Cross-contamination was evident in 28% of the samples from urine collection tanks. In tanks where the urine was found to be contaminated, it was possible to calculate the amount of faecal matter still in suspension. Using an average value of 4 µg coprostanol per mg faeces, contamination was calculated to vary between 1.6 and 18.5 mg of faeces per l urine mixture with a mean of 9.1 ± 5.6 mg/l.

Survival of microorganisms in urine

The fate of the enteric pathogens entering the urine tank is of vital importance for the health risks related to the handling and reuse of the urine. To determine the duration and conditions for sufficient storage of the urine mixture before its use as a fertiliser, it was therefore necessary to estimate the survival of various microorganisms in urine as a function of time.

Survival of bacteria

Survival studies of bacteria in urine were performed at 4°C and 20°C. Their persistence was also investigated at some different dilutions of the urine and at different pH-values. Bacteria were added or originally present in the urine mixture. At different time intervals the bacteria were enumerated and T_{90}-values (time for 90% inactivation) for the different organisms were then estimated.

Gram-negative bacteria (e.g. *Salmonella* and *E. coli*) were rapidly inactivated (time for 90% reduction, T_{90} <5 days) in source-separated urine at its natural pH-value of 9. Gram-positive faecal streptococci were more persistent with a T_{90} of approximately 30 days at 4°C. Clostridia spore numbers were not reduced at all during 80 days (figure 1). A lower temperature and a higher dilution involved a longer survival of most bacteria. pH-values the furthest from neutral had the most negative effect on survival of the organisms. At pH 6 most of the bacteria had a better survival than at pH 9. The reduction of bacteria at high pH-values may be an effect partly of the pH and partly of the presence of ammonia.

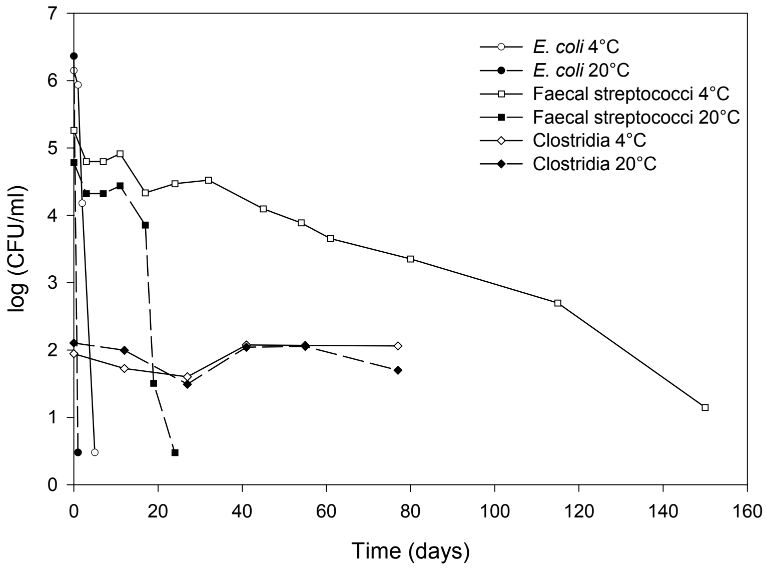


Figure 1 Inactivation of E. coli, faecal streptococci and C. perfringens spores (clostridia) in source-separated human urine (pH 9) at 4°C and 20°C

Survival of protozoa

Cryptosporidium parvum is known to be persistent in waste products as well as in water and to be resistant to disinfectants (Meinhardt et al., 1996) and was chosen as a representative to study the survival of protozoa in urine. The inactivation in buffers was investigated as a comparison to evaluate the effect of pH. Two different in vitro viability methods, excystation (Robertson et al., 1993) and inclusion or exclusion of the vital dyes DAPI and PI (Campbell et al., 1992), were used.

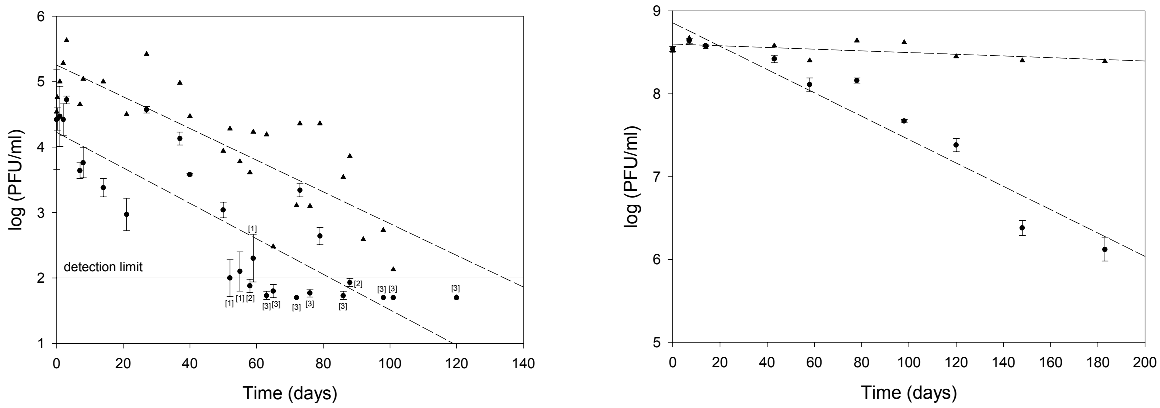
In urine mixture at pH 9 and 4°C, oocysts of the protozoa *Cryptosporidium parvum* were inactivated to below the detection limit (<1/300) within 63 days. The T_{90}-value for *Cryptosporidium* was determined at 29 days (table 1). At 20°C the T_{90} was estimated at 5 days.

By pairwise comparisons of the inactivation coefficients (*k*) it was shown that the inactivation rate of *Cryptosporidium* oocysts in urine at pH 9 was significantly higher ($p < 0.01$) than in the controls and in urine at pH 5 and pH 7, according to the dye permeability assay. In buffer solutions (pH 5, 7, and 9) there were no significant differences in inactivation rate between pH-values for methods and T_{90}-values ranged from 115 to 168 days. When correlating urine samples with the corresponding buffer samples it was only at pH 9 that the inactivation rate was significantly higher ($p < 0.01$) in urine.

Survival of viruses

To investigate virus survival, rotavirus and *Salmonella typhimurium* phage 28B were chosen as model organisms. Rotaviruses were enumerated as peroxidase stained plaques in infected MA-104 cell monolayers (reported as PFU/ml). Phage 28B was quantified by the double agar layer method. The inactivation of RRV and phage 28B were assumed to follow first order kinetics and the inactivation rate, *k* (log_{10} inactivation per day), was determined as the slope of the inactivation curves.

In summary, no significant inactivation of either rotavirus or the phage occurred at 5ºC during six months of storage, while the mean T_{90}-values at 20ºC were estimated at 35 and 71 days, respectively (figure 2, table 1). In pH-controls (pH 7), the inactivation of rotavirus was similar to that in urine at both temperatures, whereas no decay of the phage occurred at either 5ºC or 20ºC. Therefore, rotavirus inactivation appeared to be largely temperature dependent, whereas there was an additional virucidal effect on the phage in urine at 20ºC (pH 9).



a b

Figure 2 Inactivation of (a) *rhesus* rotavirus and (b) *Salmonella typhimurium* phage 28B in diverted human urine (•) and control medium (▲) at 20°C. For urine each data point is a mean of triplicate samples (three counts for each sample), error bars represent one standard deviation. For the control the data points represent one sample (mean of three counts). The dashed lines are generated from linear regression. Numbers in brackets (a) indicate the number of samples that were below the detection limit on the day of analysis

Discussion

The short survival of *E. coli* in urine makes it unsuitable as an indicator for faecal contamination. Gram-negative bacteria such as *Campylobacter* and *Salmonella* cause a majority of gastrointestinal infections. All bacteria belonging to this group were inactivated rapidly in urine mixture, indicating a low risk for transmission of gastrointestinal infections caused by bacteria when handling diverted urine.

Cryptosporidium oocysts were reduced by approximately 90% per month in the urine mixture and was considered to be the most resistant of all the protozoa. Thus other protozoa like *Giardia* and *Entamoeba* do not imply a higher risk than *Cryptosporidium*.

Viruses were the most persistent group of microorganisms with no inactivation in urine at 5°C and T_{90}-values of 35-71 days at 20°C. With the high excretion and low infectious dose of rotavirus, there is probably no other enteric virus that constitutes a higher risk. However at 20°C, phage 28B was more resistant than rotavirus, and other viruses could be equally persistent in urine. Rotavirus has been reported to be as resistant or more resistant than several other enteric viruses (Ward et al., 1989; Pesaro et al., 1995).

For source-separated human urine mainly temperature, pH, and ammonia were considered as affecting inactivation. The presence of other microbes, available oxygen and, for bacteria, available nutrients, to be small will most certainly have an effect on microbial behaviour in the urine as well. Temperature seemed to affect all microorganisms investigated. For bacteria further dilution of the urine prolonged the survival, which may be due to lower concentrations of harmful compounds. The effect of pH is difficult to separate from the effect of ammonia, except for *C. parvum* oocysts where there was no difference in inactivation in buffer solutions with pH 5, 7, and 9 and thus an additional impact of ammonia or other compound in the urine was verified. Rotavirus was neither affected by pH nor ammonia since the inactivation in buffer (pH 7) was similar to that in urine.

Table 1 Summarised results from the survival experiments given as T_{90}-values (time for 90% reduction)

	Gram-negative bacteria	Gram-positive bacteria	*C. parvum*	Rotavirus	*S. typhimurium* phage 28B
4°C	1	30	29	172[a]	1 466 [a]
20°C	1	5	5	35	71

[a] survival experiments performed at 5°C

According to Hamdy et al. (1970; in Feachem et al., 1983) urine is ovicidal and *Ascaris* eggs are killed within hours. Olsson (1995), however, reported the reduction of *Ascaris suum* in urine to be minor. The investigations of *Ascaris suum* in 4°C and 20°C indicated a reduction of 15-20% during a 21-day period. Early studies also reported inactivation of *Schistosoma haematobium* in urine (Porter, 1938; in Feachem *et al.*, 1983). Further studies of helminths including *Ascaris* is necessary, especially if the system is to be promoted in developing countries.

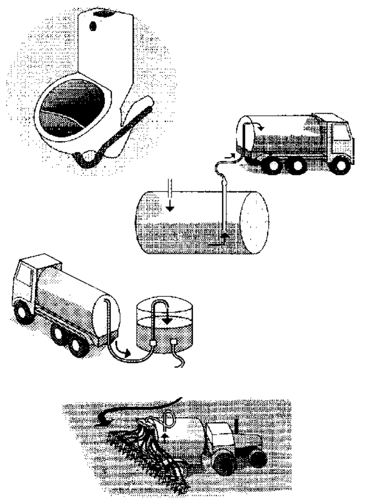
Microbial risk assessment of urine-separating systems

Quantitative Microbial Risk Assessment (QMRA) is a tool used to predict the consequences of potential or actual exposure to infectious microorganisms (Haas et al., 1999). Microbial risk assessments were first developed for drinking waters (Regli et al., 1991) and have later been applied to practices such as irrigation of crops.

Exposure scenarios

The transmission pathways investigated in the QMRA included accidental ingestion of unstored urine (1 ml); accidental ingestion of stored urine (1 ml); inhalation of aerosols while spreading the urine; and ingestion of crops contaminated by urine (figure 3). Persons at risk include inhabitants in the housing area, workers handling the urine, including farmers applying the urine to arable land, persons in the surroundings of the field, and persons consuming fertilised crops.

Calculations of the doses ingested were based on the measured faecal contamination, the incidence of infection by *Campylobacter jejuni*, *Cryptosporidium parvum* and rotavirus in the population, the excretion of these pathogens and their inactivation in urine mixture. Finally, the risks of infection were calculated by using dose-response models.



Exposure	Risk
Cleaning of blocked pipes	Ingestion of pathogens
Accidental ingestion when handling unstored urine	Ingestion of pathogens
Accidental ingestion when handling stored urine	Ingestion of pathogens
Inhalation of aerosols created when applying urine	Inhalation of pathogens
Consumption of crops fertilised with urine	Ingestion of pathogens

Figure 3 Exposure pathways in the urine-separating system investigated in the microbial risk assessment

Quantitative risks

Except for rotavirus, calculated risks were below 10^{-3} (1:1 000) for all exposure routes independent of the urine storage time and temperature evaluated (table 2). Due to the persistence of rotavirus at low temperatures (≤5°C) and a low infectious dose, risks for rotavirus infection were up to 0.56 by ingestion of unstored and stored (4°C) urine. If stored at a higher temperature (20°C) for six months, the risk for rotavirus infection decreased to below 10^{-3}. The risk for *Campylobacter* infection was negligible ($<10^{-15}$) except if unstored urine was handled or used for fertilising. *Cryptosporidium* constituted a lower risk in unstored urine than *Campylobacter*, but six months storage at 20°C was needed for risks to be negligible.

Table 2 Calculated risks, means, and (standard deviations) for a single exposure by accidental ingestion of urine and inhalation of aerosols in the worst-case scenario

Pathways	Storage conditions	*C. jejuni*	*C. parvum*	Rotavirus
Accidental ingestion	unstored	4.8×10^{-4} (3.7×10^{-3})	8.7×10^{-5} (8.4×10^{-4})	5.6×10^{-1} (2.2×10^{-1})
	1 month 4°C	nr	1.6×10^{-5} (1.8×10^{-4})	5.6×10^{-1} (2.2×10^{-1})
	6 months 4°C	nr	2.6×10^{-8} (5.5×10^{-7})	5.6×10^{-1} (2.2×10^{-1})
	1 month 20°C	nr	6.9×10^{-11} (6.8×10^{-10})	3.3×10^{-1} (2.4×10^{-1})
	6 months 20°C	nr	nr	5.4×10^{-4} (5.7×10^{-3})
Aerosol inhalation	unstored	1.2×10^{-4} (9.6×10^{-4})	2.0×10^{-5} (2.0×10^{-4})	4.2×10^{-1} (2.4×10^{-1})
	1 month 4°C	nr	3.6×10^{-6} (4.3×10^{-5})	4.2×10^{-1} (2.4×10^{-1})
	6 months 4°C	nr	6.0×10^{-9} (1.3×10^{-7})	4.2×10^{-1} (2.4×10^{-1})
	1 month 20°C	nr	1.6×10^{-11} (1.6×10^{-10})	2.0×10^{-1} (2.0×10^{-1})
	6 months 20°C	nr	nr	1.4×10^{-4} (2.2×10^{-3})

nr = negligible risk ($<10^{-15}$)

The risk from ingestion of contaminated crops will be dependent on the time that passes between fertilisation and harvest of the crop, i.e. consumption, since pathogen inactivation will continue on the crop due to UV-radiation, desiccation, etc. In figure 4, the risks from consumption of crops one to four weeks after fertilising with unstored urine are presented. The risk for bacterial or protozoan infection was $<10^{-5}$ after one week, whereas three weeks were needed for the risk of viral infection to be of the same magnitude.

Acceptable risk and risk management

The acceptable risk is a key point in risk management. If a risk is considered to be too high, preventive measures can be taken to decrease the risk to the acceptable level or the practice may not be approved, e.g. the reuse of wastewater or human urine in agriculture. The US EPA, however, has proposed a level of 1:10 000 per year for the consumption of drinking water (Regli et al., 1991). This limit has been debated and Haas (1996) argued that it should be lowered to 1:1 000 per year. The proposal of an acceptable risk limit needs to involve representatives from various parts of society and the proposal may vary depending on the present health status of the population concerned (Blumenthal et al., 2000).

Assuming that the acceptable risk for infection is 1:1 000 per year then all practices would be considered safe if occurring once a year, except for viruses. For viral risks to be less than 1:1 000 a storage time of six months at 20°C or a period of three weeks between fertilisation and consumption would be needed (table 2, figure 4). The transmission of e.g. rotavirus commonly occurs person-to-person, which implies that handling of waste products would only marginally affect the prevalence of such diseases in a society (Lewis-Jones & Winkler, 1991). Furthermore, several of the exposures will be partly on a voluntary basis that may allow for higher risks compared to involuntary exposure. If individuals are aware of the exposure they also have the possibility to protect themselves for example by wearing gloves and mouth protection when handling urine. The risk for an outbreak caused by direct contact with urine is low, since few persons are exposed, e.g. compared to a drinking water supply or recreational water.

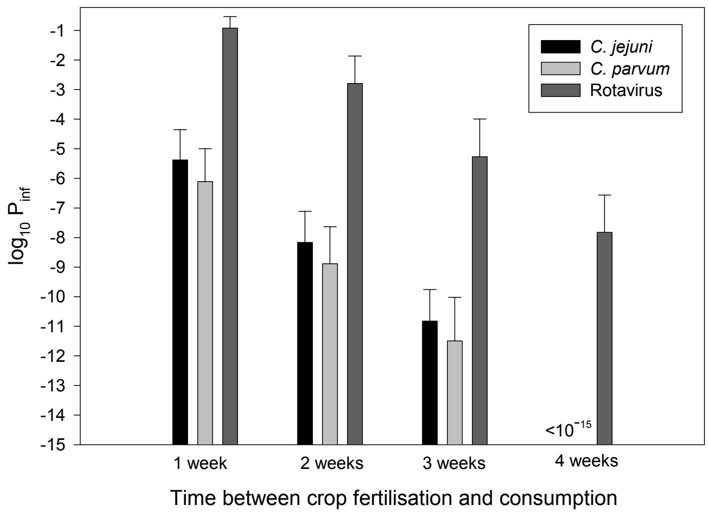


Figure 4 Mean probability of infection by pathogens following ingestion of 100 g crop fertilised with unstored urine with varying time between fertilisation and consumption. Error bars indicate one standard deviation

Guidelines for the reuse of human urine

Since urine-separating systems are being implemented in Sweden, it was decided to set reuse conditions based on the parameters, urine storage time and temperature (table 3). Guidelines may in this context be seen as recommendations on how to use source-separated urine in agriculture in order to minimise the risks of transmission of infectious diseases and as a part of risk management. Regulatory standards or guidelines have yet to be determined by the agency responsible.

These guidelines were set based on the inactivation of microorganisms in urine and the results from the risk assessment do not imply that the recommendations need to be modified. Under conditions (e.g. regarding temperature, pH and nitrogen concentration) other than those given, the inactivation may be different.

Processing of crops, using e.g. heat, will inactivate all pathogens potentially present except bacterial spores. Fertilising grasslands used for fodder to cattle with urine is not recommended since grazing animals may consume substantial amounts of soil. Similarly, the use of urine on straw to be used as bedding material is discouraged since animals may consume part of the material and since the lower parts of the plant are more exposed to microorganisms in urine and contaminated soil than the upper parts, e.g. grain.

Table 3 Relationship between storage conditions, pathogen content[a] of the urine mixture and recommended crop for larger systems[b]. It is assumed that the urine mixture has pH of 8.8 at least and a nitrogen concentration of at least 1 g/l

Storage temperature	Storage time	Possible pathogens in the urine mixture	Recommended crops
4°C	≥1 month	viruses, protozoa	food and fodder crops that are to be processed
4°C	≥6 months	viruses	food crops that are to be processed, fodder crops[c]
20°C	≥1 month	viruses	food crops that are to be processed, fodder crops[c]
20°C	≥6 months	probably none	all crops[d]

[a] Gram-positive bacteria and spore-forming bacteria are not included.
[b] A larger system in this case is a system where the urine mixture is used to fertilise crops that will be consumed by individuals other than members of the household from which the urine was collected.
[c] Not grasslands for production of fodder. Use of straw is also discouraged.
[d] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

For single households the urine mixture is recommended for all type of crops, provided that the crop is intended for the household's own consumption and that one month passes between fertilising and harvesting, i.e. consumption. Incorporating the urine into the ground is also recommended, but only for crops where the edible parts grow above the soil surface. For crops growing under the surface it is, from a hygiene point of view, more beneficial not to work the urine into the ground since inactivation of potential pathogens by heat, UV-radiation, and desiccation is faster on the surface.

For diverted urine it is recommended to use a fertilising technique that applies the urine close to the ground, not creating aerosols, since spray application implies quite high risks for viral infections and also leads to high nitrogen losses. Harrowing directly after spreading would further decrease the exposure for both humans and animals. Furthermore, collection and reuse of urine from hospitals, homes for the elderly, and also from day-care centres could be avoided since the prevalence of enteric diseases often is higher at such institutions than in the normal population.

Future perspectives

Whether urine-separation and the reuse of urine can be recommended depends on whether the associated health risks are considered to be acceptable. These risks can be balanced against benefits like the fertiliser value of human urine. Higher risks from reuse of waste products may be acceptable in areas where enteric disease is endemic and where it is transmitted through poor hygiene and sanitation (Blumenthal *et al.*, 2000). In areas where food is scarce, benefits from larger harvests may reduce other risks such as malnutrition, which otherwise causes immunosuppression and makes the individual more susceptible to infections.

Regarding the risk for pathogen transmission, there is a choice of whether to store the urine under conditions that virtually eliminate pathogens or to account for further inactivation in the field. If applied to non-food crops the foodborne route of transmission is eliminated, but there is still an infection risk for people involved in the production and processing of crops as well as for humans and animals in the surroundings. By following suggested recommendations for storage and reuse, which are dependent on the type of crop to be fertilised, it is possible to significantly decrease the risk for infections. Urine-separation and the reuse of human urine could thus be appropriate parts of a sustainable future regarding sanitation.

This paper is a summarised version of a doctoral thesis published by the author in February 2001: Höglund, C. (2001). *Evaluation of microbial health risks associated with the reuse of source separated human urine*. PhD thesis, Department of Biotechnology, Royal Institute of Technology, Stockholm, Sweden. The full thesis summary (87 pages, without papers) can be downloaded from: http://www.lib.kth.se/Sammanfattningar/hoglund010223.pdf

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Energy related to sustainable waste handling technology

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Abstract

Waste is an integral element in human life. In order to develop a more sustainable waste handling, it is necessary to review the possibilities for redesigning waste products, and for to minimising the energy consumption associated with the waste handling. In the households the physiological waste and waste produced in the kitchen can either be removed as wastewater or as solid waste. By redirecting organic kitchen waste from the wastewater stream to the solid waste, more organic matter will be available for energy production either by incineration or biogas production. Together with our possibilities for regulating the water consumption, this gives us the potential for designing waste handling and the related energy consumption. By redirecting the solid organic kitchen waste to the wastewater stream, by the use of garbage grinders, the performance of the nitrogen removal process at wastewater treatment plants can be improved. By disconnecting the toilet waste, or just the urine, from the wastewater stream, the resulting wastewater will have a nitrogen concentration so low that no nitrogen removal is needed at the wastewater treatment plant. Waste design, with the aim of reducing the energy consumption, can result in major changes in the wastewater and solid waste handling technologies in the future.

Key words

Organic household wastes, wastewater management, solid waste management, waste design, waste production per capita, energy, sustainability, households.

Introduction

Human activities will always produce waste, but it is possible to reduce the total waste discharge by applying cleaner technology in households and in industry. If fewer unnecessary products, like for example several layers of wrappings, are transported into the households the waste production can be reduced. Another possibility is to reduce the content and concentrations of hazardous chemicals present in products used in households. The amount and type of waste produced in households and industries is influenced by the behaviour of the population and the technical and juridical framework within which we can operate. For households, there are significant possibilities for changing the amounts and composition of waste generated. This will in turn affect the energy consumption and production related to water and wastewater treatment significantly. Waste from wash and bath is by nature water borne, while most of the solid inorganic household waste cannot be directed into the wastewater flow. However, organic waste from the kitchen and the toilet can either be removed from the households as wastewater or as solid waste - see figure 1. Our technological tradition decides for us, what part of the waste is solid and what part is water borne, but in order to suit the present need for more sustainable waste and wastewater handling we might have to choose different technologies, which may imply different flows of the waste. As with all changes in technologies, flexibility of the chosen solutions are essential to obtain long term sustainable solutions.

Waste from households

In the case of household waste, the composition of wastewater and solid wastes from households is a result of the distribution of contributions from various sources within the household. It is possible to change the amount and the composition of the wastes. The tool for detailed analyses of waste composition is mass flow analyses. The amount of a given waste form can be decreased or increased, depending on what the optimal solution is in the actual case.

As an example, a reduction of the amount of waste present in the wastewater can be achieved by two means

- reduction of waste generated in the household
- diversion of certain waste loads to the solid waste of the household

The amounts of organic waste and nutrients produced in households in developed countries are shown in table 1. From the table, it is easy to get an idea of the potential for changes in the wastewater composition.

Table 1 Production and composition of total (solid and waterborne) household wastes, g/(cap·day). (Based on data from Henze et al. (2001); Sundberg (1995); Danish EPA (1993), Nissen et al. (1994), Gleisberg & Hahn (1995), Eilersen et al. (1999))

Matter	Total	Physiological		Kitchen		Wash and Bath
		Faeces	Urine	Liquid	Solid	
Dry weight	235	35	60	40	80	20
COD	220	60	15	45	90	10
BOD	90	20	5	30	30	5
Nitrogen	15.7	1	11	1	1.7	1
Phosphorous	2.8	0.5	1.5	0.2	0.3	0.3
Potassium	4.7	1	2.5	0.4	0.4	0.4

Physiological waste

It is not possible to reduce the amount of physiologically generated waste. Disconnecting the toilet waste from the waterborne route will result in a significant reduction in the nitrogen, phosphorus, and organic load to the wastewater. Toilet waste disconnected from the common wastewater route still needs to be transported out of the household, and in many cases out of the city. Different technologies for handling this sort of waste exist. Among the possibilities are:

- night soil system, known from all over the world, but technically mastered in Tokyo,
- compost toilets, known from households in agricultural areas and weekend cottages,
- ceptic tanks followed by direct infiltration.

Recently a significant interest for separating of the urine from the toilet waste has developed, due to the high nutrient content in the urine (Sundberg, 1995). Separate collection of urine can be combined with all the above mentioned technologies. In table 1, it can be seen that urine is the main contributor to nutrients in household waste.

Liquid kitchen wastes

Waste from kitchens includes a significant amount of organic matter, some of which traditionally ends up in the wastewater. It is possible to divert part of the liquid kitchen wastes to the solid waste fraction by clean-tech cooking, thus obtaining a significant reduction in the overall organic load to the wastewater (Danish EPA, 1993). Clean-tech cooking means that food waste is discarded into the waste bin and not flushed into the sewer by water from the tap. The diverted part of the solid organic waste from the kitchen can be disposed of together with the rest of the solid organic wastes from the kitchen.

Solid waste from kitchen

The amount of solid waste generated by the urban population, will not be reduced significantly in our lifetime, thus we need to face that fact and select the optimal waste handling technology. Historically developed waste handling patterns need not be the optimal in today's society. The organic fraction of the solid waste from the kitchen can, either alone or combined with part of the traditionally waterborne kitchen waste be kept separate for later composting, incineration or anaerobic treatment.

Garbage grinders for handling the organic fraction of the solid waste from households is another possibility. The discharge of solid waste to the sewer does not change the total waste load produced by the household, but it will change the final destination for the waste. The handling of the organic fraction of household waste by truck often results in significant occupational health and odour problems during storage and transport. Using the sewer as a transport system for parts of the solid wastes can reduce these problems.

Wash and bath

This wastewater carries a minor load of organic material and nutrients. It can be used together with the traditional kitchen wastewater for irrigation, although one has to be aware of the high load of xenobiotic organic compounds in this kind of wastewater. Alternatively, it can be reused for toilet flushing, but then considerable treatment is demanded. Treatment is needed in order to avoid both spreading of pathogenic organism present in the wastewater and aftergrowth of bacteria in the water system for toilet flushing.

Waste transport

All waste generated in the households need to be transported from the house to a treatment and a disposal site. There are 3 means of transport:

- Truck transport (automobile)
- Sewer transport (aquamobile)
- Soil infiltration (terramobile)

Neither sewers nor soil are mobile as seen from a general viewpoint. But they act as vehicles for the displacement of the household waste. Local infiltration can be used for storm water disposal and can also take care of part of the waste generated in the household. However, most of the waste generated in urban areas still has to be transported over long distances by either truck or sewer.

The selection of the optimal means of transport action must be considered together with the treatment and disposal of the waste.

If the organic part of the solid kitchen waste is directed to the sewer system, the maximum waste transport by this means is achieved. The minimum waste transport by the sewer system will be the case where toilet waste is handled separately and part (here calculated as 50%) of the liquid kitchen waste ends up as solid waste. The minimum and the maximum waste amounts that can be transported from the households by truck and sewer are seen in table 2.

Table 2 Minimum and maximum transports of organic household waste by the two means (automobile and aquamobile (sewers)), g/(cap·d)

Transport ↓	Minimum				Maximum			
	COD	BOD	N	P	COD	BOD	N	P
Sewer	33	20	1.5	0.4	220	90	15.7	2.8
Truck	0	0	0	0	187	70	14.2	2.4

Waste design

The use of one or more of the above-mentioned waste handling technologies makes it possible to design a wastewater with a specified composition that will be optimal for its further handling. As the pollutant load is closely related to the energy consumption for wastewater treatment, the goal could be to reduce the pollutant load to the wastewater. By increasing the pollutant load to the solid waste, the possibilities for recycling of nutrients are also increased. Table 3 illustrates the possible contributions in waste loads to the wastewater and the solid waste by the different actions discussed.

Table 3 Household waste. Waste load to wastewater and solid waste by application of different technical actions, g/(cap·day)

Technology	Present		Toilet separation[+]		Clean-tech cooking[#]		Clean-tech cooking[#] + toilet separation		Garbage grinder	
Wastewater/ solid waste	water	solid	water	solid	water	solid	water	solid	water	solid
COD	130	90	55	165	107	112.5	33	187.5	220	0
BOD	60	30	35	55	45	45	20	70	90	0
Nitrogen	14	1.7	2	13.7	13.5	2.2	1.5	14.2	15.7	0
Phosphorus	2.5	0.3	0.5	2.3	2.4	0.4	0.4	2.4	2.8	0
Potassium	4.3	0.4	0.8	3.9	4.1	0.6	0.6	4.1	4.7	0

[+] Water closet → compost toilet
[#] Part (50%) of cooking waste from sink → solid waste

Water consumption and energy

The water consumption in the household is an important part of the waste generation. Water consumption by the households is the sum of 4 or 5 main fractions. The contribution from the single fractions varies with geographical location and local culture/life style. Typical present day figures from northern Europe are given in table 4. Note that infiltration in sewers is also considered as water consumption as it depletes the ground water resource, irrespectively of whether this resource is being exploited or not for the time being. Water savings and sewer rehabilitation can obtain the figures shown in the right hand column.

It is possible to reduce the water consumption for the various fractions considerably. The water consumption in the households can be reduced by 50% and even more by rehabilitation of the sewers. Water savings have two important implications on society. One is the reduced amount of energy used for the water supply and wastewater treatment, and the second is the savings of freshwater resources. The energy saving related to water savings is shown in table 5.

Table 4 Fractionated water consumption, l/(cap·day)

Water	Today	With savings
Toilet	50	25
Bath	40	25
Kitchen	50	25
Wash	10	5
Infiltration	80	25
Total	230	105

Table 5 Energy consumption for pumping and treatment of water for water supply and for pumping of wastewater in sewers and in treatment plants, related to water volume

		Water supply	Wastewater water	Total energy
Energy consumption	Wh/l	0.5	0.1	
Water supply:				
150 l/(cap·d)	Wh/(cap·d	75	15	90
80 l/(cap·d)	Wh/(cap·d	40	8	48

At wastewater treatment plants energy is also consumed for the biological processes, oxidation of organic matter, nitrification and denitrification, table 6. The energy consumption related to transportation of solid waste to deposit and energy savings related to substitution of chemical fertilizer are also important factors to be considered in an energy budget. These are given in tables 7 and 8.

Table 6 Energy consumption and production related to biological wastewater treatment. Based on data from Henze et al., 2001

Pollutant	Wh/g pollutant
Consumption:	
BOD	1.5
$NH_4^+ \rightarrow NO_3^-$	6.3
$NH_4^+ \rightarrow NO_3^- \rightarrow$	2.4
Production:	
*BOD $\rightarrow CH_4$	(3.5) 2.2
*COD $\rightarrow CH_4$	(1.4) 0.9

*Numbers in parentheses give the available energy output (heat and electricity), the number without parenthesis gives the electricity output alone

Table 7. Energy consumption related to transportation of solid waste to deposit. Pommer et al., 1993

Solid waste measured as	Wh/kg pollutant
COD	160
BOD	440

Table 8 Energy savings related to substitution of chemical fertilizer. Bundgaard et al., 1993

Nutrient	kWh/kg nutrient
Nitrogen	13.9
Phosphorous	4.4
Potassium	2.2

Transportation of the various waste products is another energy consuming factor that has to be considered in an energy balance, see table 8.

Table 8 Energy consumption for transport of organic waste products, Wh/(cap·d)

Technology	Present	Toilet separation	Cleantech cooking	Cleantech cooking	Garbage grinders
Transport of:					
Collection of solid kitchen waste	19	19	24	24	0
Sewage sludge	1.2	0.7	1.0	0.4	1.6
Toilet waste	0	8	0	8	0
Ash from incineration of solid kitchen waste	0.5	0.5	0.6	0.6	0
Total:	20.7	28.2	25.6	33	1.6

+Faeces is assumed composted and the urine collected at the household. The composted faeces and the collected urine are assumed transported to agriculture within a range of 20 km.

Energy overall

The energy budget for the different treatment scenarios can now be calculated. The energy production from incineration of, or biogas production from, solid organic waste is taken into account, whereas energy consumption for sludge treatment, including pumping, thickening and dewatering, will not be included, since it only accounts for 5-10% of the total energy consumption at the wastewater treatment plant. When all the major contributions to the energy budget for the running of the different waste handling systems have been considered, the different systems can be compared with respect to energy efficiency. This rough estimate is given in table 9. From an energy point of view, solid organic kitchen waste should be incinerated or used for biogas production, and not treated at the wastewater treatment plant after grinding. Therefore, kitchen waste should be diverted from the wastewater stream to the solid waste handling. Toilet waste, or at least the urine, should be kept separate and used as fertilizer in agriculture.

Future waste treatment

The change in wastewater and solid waste composition caused by changes in household technology will affect the treatment considerably. By removing toilet waste from the wastewater, 85% of the nitrogen and 80% of the phosphorus is removed. This means that no nitrogen removal is needed before discharge of the wastewater to receiving waters, and that only minor phosphorus removal might still be needed. An equivalent result can be obtained from separate handling of just the urine. By use of cleaner technology in the households, more organic waste can be diverted to the solid waste the solid organic waste can then be incinerated, used for production of biogas, or composted. Incineration and biogas production has an equally positive effect on the energy budget. By introducing the organic part of the solid waste into the wastewater by the use of garbage grinders, biological nitrogen removal processes will be easier to perform, because the COD/N-ratio will be increased, see table 10. The introduction of more waste into the wastewater will increase the energy needed for treatment of the wastewater. The organic material represents an organic raw material that can be used for biogas production, which may give energy production that can reduce the overall energy used for the wastewater treatment. By combining the use of garbage grinders with water savings, the wastewater can be concentrated to a level where anaerobic pre-treatment of the water, and not only anaerobic treatment of the primary sludge, will be possible and economically attractive. Never the less, in comparison to the other treatment scenarios, garbage grinders are the least attractive solution with respect to energy.

Table 9 Energy consumption and production related to different technologies for handling of household waste

Technology	Present	Toilet separation	Cleantech cooking	Cleantech cooking +	Garbage grinders
Energy consumption for wastewater handling and water supply in Wh/(cap·d):					
BOD	90	53	68	30	135
Nitrogen	34	5	32	4	38
Wastewater water	15	10	14	9	9 + 3#
Total for wastewater	139	68	114	43	185
Water supply	75	50	70	45	45
Energy production in Wh/(cap·d):					
*Biogas prod. wastewater treatment	70 + 30	41 + 18	53 + 23	23 + 10	200 +54
Biogas prod. - solid org. kitchen waste	0	180	225	225	0
Incineration - solid org. kitchen waste	200	0	0	0	0
Energy saving in Wh/(cap·d):					
Substitution of chemical fertilizer	42	192	38	188	46
Energy consumption for transportation in Wh/(cap·d):					
	21	28	26	33	2
Total energy production	107	285	129	325	68

* The production of energy from the primary sludge is estimated to be equal to 1/3 of the BOD in the raw wastewater plus savings of 1/3 of the energy for BOD oxidation. With the application of garbage grinders it is assumed that 60% of the organic material can be transformed into methane by anaerobically pre-treatment.

Garbage grinders use 3-4 kWh/(household·year), equivalent to 3 Wh/(cap·d), (Karlsberg & Norin (1999)).

Table 10 Example of COD/TN ratios in raw wastewater by various wastewater designs

Wastewater design	COD/TN ratio g COD/g TN
- traditional	10
- toilets separated	27
- toilets separated + cleantech cooking	21
- traditional + garbage grinders	15

Conclusions

In the case of household wastes, there is a big potential, both in wastewater design and solid waste design. It is possible to manipulate the water and the pollution loads entering the wastewater to obtain a wastewater of almost any conceivable composition. Water savings, sewer network renovation, disconnection of toilet wastes, solid waste manipulations in the kitchen, and the use of phosphate free detergents are the main techniques to be applied in households in order to design the waste composition. Waste design made meant to reduce the energy consumption in wastewater treatment plants can change the wastewater composition to a degree where it can result in significant changes in the wastewater treatment technology in the future. However, as energy savings at one place in the waste handling often will result in increased energy consumption at other locations, it is important to look at integrated solutions for solid waste and wastewater handling. When waterborne and solid waste is both considered, as much of the kitchen waste as possible should be handled as solid organic kitchen waste. The solid organic waste should either be incinerated or used for biogas production, and should not be treated at the wastewater treatment plant after grinding. The urine, or all the toilet waste, should be kept separate and used as fertilizer in agriculture.

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Evaluation of different biological waste treatment strategies

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Abstract

Biological treatment of organic waste by aerobic composting and anaerobic digestion (biogas production) was compared with respect to a number of environmental effects and sustainability criteria including energy balance, nutrient recycling, global warming mitigation potential, emission of xenobiotic compounds, and economy. The parameters were assessed based on case studies in the literature as well as our own research. Assessment of energy balance, nutrient recycling, and global warming came out in favour of biogas production, but especially the results regarding estimation of global warming mitigation differ from the assumptions made. Our calculations show that a fugitive loss of approx. 14% of the biogas produced by anaerobic digestion will turn the scale in favour of composting regarding global warming mitigation. In Europe actual biogas losses from 3.5 to 8.4% are reported, but this may be exceeded in developing countries. Regarding emission of xenobiotic compounds composting is much in favour, as recent experiments show that a number of organic micro-pollutants are rapidly degraded during composting as opposite to anaerobic treatment. In most cases composting is more cost-effective compared to biogas production, but estimations of actual costs differ considerably. Published results of Life Cycle Assessment of organic waste management using the ORWARE model showed biogas production to have less environmental impact in general than composting, but it was demonstrated that changes in e.g. system boundaries or functional units may result in substantial differences on the conclusions as well. In conclusion, the optimum waste planning strategy may be the implementation of an integrated waste treatment system operating with different scales of composting and anaerobic treatment, depending on local conditions.

Keywords: Composting, biogas, anaerobic digestion, environmental effects, global warming, xenobiotics, energy, system analysis.

Introduction

Biological treatment of organic waste is an age-old practice that in relation to municipal solid waste has had a strong revival during the last decade. This is due to increased efforts to improve recycling of nutrients and organic matter to soil and in particular to minimise landfilling of biodegradable waste to reduce emission of greenhouse gases. In addition, special attention is given to the possibility of utilising the energy liberated during microbial decomposition of organic matter. Thus, the ultimate objective of biological waste treatment is to optimise the resource and energy use and simultaneously minimise the environmental impacts at the lowest possible investment and operational costs. The ideology behind this is supported at the highest political levels, e.g., the European Commission has recently proposed a directive with the intent of making biological waste treatment obligatory within the next few years.

Biological waste treatment can be carried out in two principally different ways: by anaerobic digestion, i.e. biogas production, or by composting. In industrialised countries biogas is traditionally produced in high-tech plants with a capacity of processing many thousands tons of waste per year. This is not always the case in developing countries where small-scale low-tech biogas plants may dominate. Composting is a more or less controlled aerobic microbial decomposition process that, in industrialised countries as well, is organised at very different scales and technological levels, from a simple heap or bin in the backyard to high tech in-vessel systems of very large capacities.

A generic assessment of functional differences between biological waste treatment systems is a difficult but important task as foundation for political decision making. Political reflections are most commonly made on a few, simple scenarios, if any at all. A more comprehensive background for implementing new waste systems can be generated by system analysis. Systems analysis including modelling to compare different biological treatment strategies has been practised in Sweden for some years. The ORWARE model (e.g. Dalemo, 1999, Sonesson, 1998) has been developed to evaluate environmental effects and energy turnovers for different biological waste treatment systems aiming at recycling as many nutrients as possible to arable land. Systems analysis, though, is vulnerable to lack of relevant data. Thus, data might origin from malfunctioning treatment plants or they may be totally lacking, so that assumptions have to be made. Other factors of great importance are the definition of system boundaries, functional units, and supplementary production.

The aim of the present study is to evaluate and compare different biological waste treatment strategies with respect to various parameters including energy balance, nutrient recycling, environmental impacts, and economy. This is done based on a literature review of individual case studies supplemented with data from our own studies on degradation of xenobiotic compounds during composting. In addition, some of the published results of the ORWARE model are discussed.

Evaluation of strategies based on case studies

Energy balance

At the technical level of today it is not possible in practice to utilise the energy generated during the composting process in other ways than to accelerate the microbial process itself and to sanitise the waste during the process. Biogas production should therefore - isolated seen - result in a better energy balance than composting independent of how the energy is utilised.

Another aspect of the energy balance is related to transportation. Urban ecologists, environmental grass roots, and others often point to the energy consumption and the emissions related to the transport work. Nevertheless, the energy consumption from waste collection and transportation of endproducts is in general of minor importance compared to other effects of the waste system including the energy production from biogas plants (or incinerators) (Sonesson, 1998). For example, within a distance from sources to plant of up to 50 km, energy used for transport constitutes only 12-16% of the energy produced (Börjesson, 1997). Also the environmental impacts from transportation are of minor importance in relation to the impact of the whole waste treatment system. Minimising transport seems more important for lowering costs, accidental risks, and noise effects (Sonesson, 1998).

Nutrient recycling

Compost is generally more stabilised than the anaerobic residues. Therefore, it is also more attractive (both in relation to appearance and odour) and easier to apply to the soil, at least for laymen. The water-soluble nitrogen concentration is higher in the anaerobic digestate, but loss of ammonia during spreading and immobilisation of nitrogen in the soil afterwards result in a smaller difference in fertiliser effect than reflected by the product declarations. Furthermore, some of the organically bound nitrogen in compost is mineralised after applying the compost to the soil (Thomsen and Olesen, 2000).

Environmental impacts

Global warming potential from greenhouse gas emission

Mitigation of greenhouse gas emission is one of the main reasons for diverging organic waste from landfills to biological treatment facilities. The following calculations are, therefore, carried out in some detail.

In theory, anaerobic digestion as well as composting reduces greenhouse gas emission by 100% compared to landfilling of organic waste. Another aspect of greenhouse gas mitigation is the replacement of fossil fuel by the produced biogas: The net energy gain from biogas production can be estimated to 2000 MJ t^{-1} waste (Anon., 2000). Using a conversion factor of 77 kg of CO_2 released per GJ of energy produced from oil (IPCC, 1996), the substitution of fossil fuel thus corresponds to 154 kg CO_2 equivalents t^{-1} of waste. To achieve this, CH_4 must be totally converted to CO_2 during energy production, but it has been estimated (Danish EPA, 1997) that an average of 3.5% of the produced fuel is lost to the atmosphere as fugitive emissions due to incomplete combustion or leaks in biogas engines. This is in contrast to Dalemo (1999) who, based on older data, estimates the fugitive emission from biogas engines to 0.10 g CH_4 MJ^{-1} corresponding to 4.2 kg CO_2 equivalents t^{-1} of waste. Assuming an average biogas production from organic waste of 120 Nm^3 t^{-1} with a CH_4 content of 65% (Anon., 2000) a 3.5% loss will constitute approx. 2 kg CH_4 t^{-1} of waste. This corresponds to 42 kg CO_2 equivalents t^{-1} if the 100 year conversion factor of 21 for CH_4 (Ayalon et al., 2000) is used. As a consequence, the total greenhouse gas mitigation effect of biogas production – assuming a 3.5% loss - constitutes 154-42 = 112 kg CO_2 equivalents t^{-1} of waste.

The above mentioned gas loss of 3.5% from biogas combustion is calculated for state-of-the-art combustion engines, but this type of equipment may not always be at hand, especially in developing countries. As an example, the Indian state Himachal Pradesh has installed more than 35,000 biogas-plants at small farmers from 1982 to 1995 (Singh et al., 1997). In 1995 less than 50% of the plants were working due to incorrect handling, lack of maintenance and spare parts, etc. Presumably, the gas loss from this type of plants and the corresponding biogas engines vastly exceeds 3.5% and will, therefore, constitute a significant contribution to the total green house gas emission from India.

Cumby et al. (2000) measured fugitive biogas loss from digesters on farms in the UK and found losses from 3.4 to 8.4% of the produced CH_4. Thus, the above mentioned fugitive loss of 3.5% from biogas engines may be an underestimation of the actual loss, at least in farm-based systems.

Data on methane emission from composting of MSW are scarce, but Hellmann et al. (1997) measured CH_4 emission rates between 0 and 1,400 mg CH_4-C hour^{-1} t^{-1} (dry weight) of waste during windrow composting of MSW mixed with yard clippings. Using an average emission rate of 700 mg CH_4-C hour^{-1} t^{-1} of waste for a duration of 25 days (the period where CH_4 emission was detected) this corresponds to a total emission of 0.56 kg CH_4 t^{-1} of waste. Converted to fresh weight basis CH_4 emission from composting of MSW can thus be estimated to 0.22 kg CH_4 t^{-1} of waste corresponding to 4.6 kg CO_2 equivalents t^{-1}of waste.

It has to be stressed that another greenhouse gas, N_2O, can be emitted during composting, but according to Hellman et al. (1997) the emission rate of this gas was much lower than the emission rate of CH_4. Performing the same calculation as for CH_4 we estimate the emission of N_2O in this particular case to 0.025 kg N_2O t^{-1} of waste. The global warming potential of N_2O is 310 times that of CO_2, thus the greenhouse effect of N_2O emission from composting was 7.8 kg CO_2 equivalents t^{-1}of waste. The combined greenhouse effect of MSW composting from CH_4 and N_2O emission thus corresponded to approx. 12 kg CO_2 equivalents t^{-1}of waste.

The above calculations are based on one specific case of windrow composting of MSW reported in the literature. Another approach to estimate greenhouse gas emission from composting is to use general conversion factors related to the amounts of C and N initially present in the waste. Beck-Friis (2001) supplies general information on greenhouse gas emission from the composting process and cites estimates of CH_4 and N_2O emission levels of 1 and 0.5% of the C and N initially present. Using typical values of C and N content of source separated MSW (Smårs et al., 2001) this corresponds to a greenhouse gas emission of CH_4 and N_2O of 34 and 17 kg CO_2 equivalents t^{-1}, respectively, which adds up to 51 kg CO_2 equivalents t^{-1} of waste. This is more than four times the emission calculated from the results presented by Hellmann et al. (1997) underlining the uncertainty associated with estimation of greenhouse gas emission from composting.

In conclusion, biogas production has a larger mitigation effect on greenhouse gas emission than composting largely due to fossil fuel substitution, but loss of CH_4 during the utilisation of biogas may alter this. Compared with composting, the break-even point is reached at an emission of approx. 154 (fossil fuel substitution from biogas)+12 (low estimate of net greenhouse gas emission from composting) = 166 kg CO_2 equivalents t^{-1} of waste from biogas production equalling approx. 14% loss of the produced biogas to the atmosphere. This can probably be avoided in industrialised countries, but the more low-tech solutions that are being promoted in developing countries can diminish the global mitigation effects.

Xenobiotic compounds

A prerequisite for utilising the endproducts from biological treatments is the absence of xenobiotic compounds in concentrations that will make the product unsafe for man and the environment. Regulation in Denmark prevents use of waste products in agriculture if one of the following four types of organic micro-pollutants are present in concentrations exceeding the stipulated limits: the plasticiser DEHP, the detergents LAS and NPE, and the sum of nine PAHs (Danish EPA, 2000). It is worth noticing, that the regulation is based on the concentration of pollutants in the raw waste, but this issue is presently being debated and some exemptions based on the concentration in the endproduct have been given by the authorities.

A number of reports have focused on biological degradation of xenobiotic compounds during composting as well as on production of biogas. Under anaerobic conditions - biogas production – complex organic molecules are generally recalcitrant. Examples are the incomplete anaerobic degradation of NPE leaving the aromatic ring structure of the ultimate degradation product intact (Ejlertsson et al., 1999) and the persistence of DEHP in anaerobic sewage sludge (Battersby and Wilson, 1989). In contrast, composting increases degradation of organic micro-pollutants. Thus DEHP and LAS were degraded to safe levels in less than two weeks by composting of MSW and sewage sludge, respectively (Møller et al., in press, Møller and Reeh, submitted). NPE and PAH were also degraded, but at slower rates than the former compounds. Composting thus has a clear advantage over biogas production with respect to degradation of xenobiotic compounds.

Recently, a Swedish investigation has documented the presence of another group of organic micro-pollutants in waste products: a number of pesticides, the use of which is not allowed in Sweden, were found in compost and anaerobic sludge made from the same waste (Nilsson, 2000). Ongoing investigations focus on the possibility of optimising the composting process to promote degradation of these types of compounds.

Economy

Table 1 shows examples of calculations of financial costs of waste treatment by composting and biogas production, respectively. In three of the four references biogas production comes out as the more expensive treatment, but there is no agreement on the actual costs or on the relative differences between the cost of composting and biogas production. Eriksson et al. (in press) have used the ORWARE model to calculate the financial cost of organic waste treatment in the community of Älvdalen. Here composting proved to be marginally more expensive than biogas production. Consequently, there is no overall agreement of financial cost, but in most cases composting is estimated to be the more cost-effective strategy.

Table 1 Examples of financial costs associated with treatment of organic waste by composting and biogas production

Cost of treatment of 1 ton of waste		
Composting	**Biogas production**	**References**
800 DKK (Windrows)	1,740 DKK (High solid anaerobic digestion process). Gas sold for energy production)	Anon., 2000
1,956 SEK (Windrows)	1,887 SEK[2] (Gas used in busses)	Eriksson et al., (in press)
339 DKK (Aerated windrows)	348 DKK (Gas sold for energy production)	Danish EPA, 1997
0.58 USD[1] per ton CO_2 equivalents mitigated. (Windrows)	2.59 USD per ton CO_2 equivalents mitigated (Gas flared)	Ayalon et al., 2001

1 One USD=8 DKK.
2 One SEK=0.80 DKK

Need for end-use area

True recycling of organic waste will always demand enough acreage so that the amount of nutrients in the processed waste can be utilised in an environmentally sound manner, i.e., minimising leaching and emission and maximising plant uptake. Therefore, the most successful Danish biogas plants today are run in close co-operation between municipalities and groups of farmers in the vicinity of the plant. The farmers then guarantee to take the end-product and spread it on their farmland in accordance with the national legislative guidelines, i.e. a maximum application rate of 170 kg N ha^{-1}, 30 kg P ha^{-1} or 7 ton dry matter ha^{-1}. Similarly, multifamily dwellings must have enough amenity areas to spread locally produced compost. According to the same guidelines, there should be at least 10 m^2 of green area available per dweller to recycle the composted vegetable fraction of the household waste, an area that can be reduced proportionally according to the achievable collecting efficiency (Reeh, 2001).

Normally, purchasers of biogas residues are taking big bulks of material using large vehicles, often on a regular basis. On the contrary, more than half of the Danish compost production is disposed of using passenger cars or small vans by private garden owners. These aspects are important for the amount of transport labour associated with composting and biogas production, but the quantitative consequences are difficult to estimate.

Control of incoming waste and quality of endproducts

Quality control of incoming waste seems increasingly needed the bigger and more technically advanced the plant becomes, irrespective of whether the processing method is aerobic or anaerobic. In some ways, pre-control of incoming waste is easier to organise, but when it comes to identification of contaminating sources and prevention the difficulties arise. In this respect, local and especially home composting is in favour. Most home composting households will be very motivated to sort their biodegradable waste correctly since they are going to use the resulting compost themselves. In case of any wrong sorting the persons responsible can easily be identified and corrected. Thus compost produced at, or near the source, has in general a lower content of visible inerts and heavy metals than compost form centralised plants (Reeh, 2001).

Educational potential

Since composting is more easily downscaled compared to biogas production, composting systems can be placed close and visible to the public and therefore demonstration of the process and engaging people in recycling of organic waste can be accomplished. Moreover, due to the aerobic nature of the composting process, visitors to composting plants are able to experience the process at closer quarters than at biogas plants where the material have to be enclosed to maintain anaerobic conditions. Home composting, in particular, offers the possibility to convey a "hands-on" experience to children as well as adults regarding recycling of organic waste.

Evaluation of strategies based on system analyses: the ORWARE model

The ORWARE model uses a Life Cycle Assessment methodology and categorises some consequences of emissions in impact categories: Global warming, eutrophication, acidification, photochemical oxidants, and human health (not including working environment).

As expected, the ORWARE model in every case turns out with a better energy balance for biogas than composting, while the results regarding nutrient balance and especially the environmental impacts are more ambiguous.

Sonesson (1998) explains how in a first approach (in-vessel) composting came out with the least total environmental effects of the modelled treatment scenarios. Biogas production resulted in equal or nearly as low effects only with respect to global warming and eutrophication potential. With respect to nutrient recycling, the biogas- and composting scenario showed equal effects on phosphorus while biogas production turned out slightly better regarding nitrogen. As described elsewhere it is very important to include the spreading procedure and the soil-plant system when evaluating the degree of recycling of nutrients.

In a later study, also presented by Sonesson (1998), the boundaries/functions of the model were widened to include co-digestion of animal manure from an area in the surroundings of the city in question as well as fuelling busses with methane. The optimal treatment method then moved in favour of anaerobic digestion compared to composting. Thus global warming potential, acidification, and the recycling ratio of both nitrogen and phosphorus were in favour of biogas production. Still composting resulted in lower emissions of photochemical oxidants while the eutrophication effects were of similar size.

Conclusion

Functional differences between organic waste treatment systems based on composting compared to anaerobic digestion seems to be small in many aspects. In fact, differences between systems with the same kind of waste treatment principle might be bigger. The differences may reflect specific local conditions, such as the degree of public participation in source separation schemes, the actual design of the plant in question, the access to farm yard manure, and the access to district heating systems.

Using system analysis, preference of one treatment method to another can actually change with changes in system boundaries, including functional units and supplementary means of production. Still a detailed systems analysis seems to be an excellent tool to understand the consequences of implementing different waste management strategies and improve the overall functioning in an order of priority. To do this the model should – as the ORWARE model - be able to combine different treatment options and thereby reflect the complex reality that might lead to the optimal result from a broad sustainability perspective.

It is still an open question whether the technical development can equalise, or even turn, the principal differences in environmental impact and sustainability that we find today in clear favour of one process or the other, but at least the following points can be made:

- With existing technology, biogas production is favourable to composting regarding energy production
- Biogas production has a mitigation effect on greenhouse gas emission due to fossil fuel substitution, but this effect may be diminished by fugitive CH_4 loss from biogas engines and storage facilities.
- In most cases, composting is more cost-effective, but the actual economy is very much dependent on the technological level and transport distances.
- In Denmark, at least, it is a prerequisite for recycling of organic waste to agriculture that the concentrations of organic micro-pollutants are below certain limits. In respect to this, composting is very much in favour because of the high potential for degradation of this type of compounds.

These point, and especially the last one, may in fact lead to the implementation of integrated solutions in the future where composting and biogas production are combined in order to minimise environmental impacts and increase sustainability of biological waste treatment.

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Agriculture in Vienna - nutrient balances

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Abstract

Nutrient balances are a suitable tool for quantifying nutrient losses. The objective of this study was to assess the nutrient status in fields of arable farming, field growing of vegetables, and viticulture in Vienna. For the nutrient balances, the soil surface balance method was used. The calculations showed nitrogen balance surpluses of +40 kg ha^{-1} yr^{-1} for arable farming. Viticulture and field cropping of vegetables showed higher surpluses (+52 and +71 kg ha^{-1}, respectively) due to low output in viticulture and to the intensive cultivation in vegetable growing. The phosphorus balances were more or less even. The same was true for the potassium balances except for vegetable growing, which showed a potassium surplus of 27 kg ha^{-1}. Due to the method of calculation, these values are minimum values, assuming that all farmers follow the fertilization guidelines.

Presently, organic fertilizers make up only a small percentage of the fertilizers used. Due to the low livestock density, only a small portion of the nutrient requirements can be supplied through manure. A total of 39,700 t compost was available in 1999, but compost is used by the farmers only to a small extent.

Introduction

Vienna, the capital of Austria, has 8,824 ha of agricultural land, including 706 ha vineyards and 460 ha fields for vegetable production (ÖSTAT, 1999a, b). The major part of the agricultural area is managed in the 'conventional' way, only 11 farms with a total of approx. 500 ha are managed according to ecological farming practices. Nutrient balances are a suitable tool for quantifying nutrient losses, both at farm level and at a regional level. The first aim of this study was to calculate nutrient budgets for Vienna's agriculture including mineral and organic fertilizers and the atmospheric deposition. A second aim was to provide an overview of the amount of organic fertilizers that are available in Vienna.

Materials and methods

Nutrient budgets for Vienna's agriculture were calculated for nitrogen, phosphorus, and potassium in the fields of arable farming, field growing of vegetables, and viticulture. The soil surface balance method was used following the model of the nitrogen balance for Austrian agriculture according to the OECD criteria (Götz, 1998).

The soil surface balance calculates the difference between the total quantity of nutrient inputs entering the soil and the quantity of nutrient outputs leaving the soil annually.

The estimate of the total annual quantity of nutrient inputs for the soil surface nutrient balance includes the addition of:

- Inorganic fertilizer: quantity consumed by agriculture.
- As there are no statistical data for fertilisers available for Vienna, the fertiliser input was calculated for every crop on the basis of the respective agricultural area (ÖSTAT, 1999a,b) and the Austrian guidelines for proper fertilization (BMLF, 2000; BMLFUW, 2001). Average soil contents of phosphorus and potassium (Anonymus, 1994; Labor Pottmann, 2001; Wr. LWK, 2001) were taken into account to estimate the appropriate level of phosphorus and potassium fertilization.
- The amount of fertilizer calculated as described above was reduced for the nutrient content in the manure (for N: 70% of the N content; BMLF, 2000).
- Livestock manure nutrient production: total number of live animals (cattle, pigs, sheep, goats, poultry, horses, and other livestock) in terms of different categories according to species (e.g. chickens, turkeys), sex, age and purpose (e.g. milk cows, beef cattle; ÖSTAT, 1999a) multiplied by respective coefficients of the quantity of nutrients contained in manure/animal/ year (Götz, 1998; Galler, 1998).
- Nutrients from recycled organic matter: quantity of compost applied to agricultural land (Maurer et al., 2000) multiplied by a single coefficient of nutrient content of compost (Maurer et al., 2000).
- Atmospheric deposition of nutrients: total agricultural land area (ÖSTAT, 1999) multiplied by a single coefficient of nutrients deposited/hectare (Götz, 1998; Puxbaum und Gregori, 1998; not included in the phosphorus balance).
- Biological nitrogen fixation: area of legume crops (e.g. field beans, soybeans, clover, alfalfa; ÖSTAT, 2000) multiplied by respective coefficients of nitrogen fixation/ha (Götz, 1998) plus the nitrogen fixation by free living soil organisms computed from the total agricultural land area multiplied by a single coefficient of nitrogen fixation/ha (Götz, 1998).
- Nutrients contained in seeds and planting materials: quantity of seeds and planting materials (e.g. cereals, potato tubers; ÖSTAT, 1999a; BLF, 2000), multiplied by the respective coefficients of nutrient content of seeds/planting materials (Götz, 1998; Früchtenicht et al., 1993).

The estimate of the total annual quantity of nutrient outputs for the soil surface nutrient balance includes:

- harvested crops and forage: quantity of harvested crop and forage production (ÖSTAT, 1999a,b) multiplied by respective coefficients of nutrient content of the harvested crop and forage (Götz, 1998; Früchtenicht et al., 1993; Elmadfa et al., 1998).

The soil surface balance method is appropriate at a regional level; nevertheless, farm gate balances, which include the input of fodder and output of animal products, and which also cover the nutrient losses before manure application on fields, can be an important check-point for the soil surface balances, as shown by Granstedt (2000).

Furthermore the amount of organic fertilizers which are available in Vienna was investigated. Livestock numbers were obtained from ÖSTAT (1999a) and nutrient loads in the manure calculated as described above.

A survey was made of the amounts of compost, which was produced and used in Vienna (reference year 1999). In Austria, source separation and composting of separately collected organic waste have been obligatory since 1995. Data were collected from public services and private enterprises (gardeners, landscape gardeners, tree nurseries, waste disposal enterprises), from the Chamber of Agriculture and from organic and 'conventional' farmers.

Sewage sludge was not included in the survey, because it is not allowed to apply sewage sludge on agricultural land in Vienna.

Results and Discussion

Nutrient balances

Nitrogen balances

The nitrogen balance for arable farming showed a nitrogen surplus of 40 kg ha^{-1} per year (table 1). The main nitrogen inputs were by inorganic fertilizers (66% of the total inputs), whereas manure and compost played a minor role (9% and 6% of total inputs, respectively). Atmospheric deposition accounted for 13% of the total inputs.

Table 1 Nitrogen balance of arable farming, field growing of vegetables, and viticulture in Vienna (kg N ha^{-1} yr^{-1})

	Arable farming (kg N ha^{-1} yr^{-1})	Field growing of vegetables (kg N ha^{-1} yr^{-1})	Viticulture (kg N ha^{-1} yr^{-1})
Inputs	137.6	176.4	60.4
Inorganic fertilizers	90.7	142.2	32.8
Manure	11.7	11.7	5.6
Organic products (compost)	8.3	-	-
Atmospheric deposition	18.0	18.0	18.0
Biological nitrogen fixation	6.1	4.5	4.0
Seeds and planting material	2.8	-	-
Outputs	97.4	105.7	8.9
Total harvested crops and forage	97.4	105.7	8.9
Balance (inputs minus outputs)	40.2	70.7	51.5

The nitrogen surplus of 40 kg ha^{-1} appears to be relatively low. The low value is explained by the fact that most of the agriculture in Vienna is stockless arable farming and arable farming always has a much higher nutrient efficiency and therefore lower nutrient surpluses than animal production (Isermann, 1994). The Viennese people, however, are mostly not vegetarians and the nutrient surpluses induced by the corresponding livestock occur outside Vienna.

For field growing of vegetables, the nitrogen balance showed a surplus of 71 kg ha^{-1} due to the higher intensity of cultivation. The main nitrogen inputs were inorganic fertilizers

(81% of the total inputs). Manure provided a minor input (7% of total inputs). Compost is usually not used in field cropping of vegetables. Atmospheric deposition made up 10% of the nitrogen inputs.

For viticulture, the nitrogen balance showed a surplus of 52 kg ha^{-1}, although it was assumed that newly established vineyards were not fertilized with nitrogen. The major input was through inorganic fertilizers (54% of total inputs). Compost is usually not used in viticulture. The nitrogen removal with the grapes is very low (25 - 30 kg N for a yield of 100 hl ha^{-1}; KTBL, 1986).

Due to the calculation method for fertilizer input based on the "guidelines for proper fertilization" (BMLF, 2000) and on soil nutrient contents of phosphate and potassium, the balance results of all three nutrients must be regarded as minimum values, because this calculation assumes that all farmers follow the "guidelines for proper fertilization".

All three branches of Vienna's agriculture showed higher nitrogen surpluses than the nitrogen balance for Austrian agriculture according to OECD criteria, which yielded a surplus of 30 kg N ha^{-1} (Götz, 1998). This balance, however, is calculated using the total agricultural area of Austria, including areas which are not fertilized at all, such as alpine meadows and pastures. Furthermore, 15% of the nitrogen present in manure is subtracted as "destruction and evaporation of manure", so that these N-losses do not show up in the balance. The Austrian nitrogen balance calculated without these assumptions gave an average annual nitrogen surplus of 46 kg ha^{-1} (Götz, 1998). Agricultural nitrogen balances for other European countries, calculated by the soil surface balance method, revealed N surpluses ranging from 99 to 367 kg N ha^{-1} (Isermann, 1994). The nitrogen balances are typical for each type of farming: arable farms typically show nitrogen surpluses of 30 - 40 kg ha^{-1}, whereas animal producing farms have nitrogen surpluses between 55 and 320 kg ha^{-1}, depending on the stocking density (data based on representative supply/withdrawal balances; Isermann, 1994). Organic farms, also organic farms keeping livestock, usually show negative to slightly positive nitrogen balances at farmgate level (Kaffka and Koepf, 1989; Hege and Weigelt, 1991; Wieser et al., 1996).

Phosphorus balances

The phosphorus balance for arable farming was slightly negative with -8 kg ha^{-1} P_2O_5 (table 2). This results from the calculation of the nutrient input according to the guidelines for proper fertilization (BMLF, 2000). As the plant-available soil P_2O_5 content (measured using the calcium-acetate-lactate method) in arable farming in Vienna was between 110 and 400 mg kg^{-1} on average (Anonymous, 1994), the guidelines propose a very low level of phosphate fertilization. Half the P_2O_5 inputs were through inorganic fertilizers, one third through manure. Compost accounted for 12% of the input.

Table 2 Phosphorus balance of arable farming, field growing of vegetables, and viticulture in Vienna (kg P_2O_5 ha^{-1})

	Arable farming (kg P_2O_5 ha^{-1} yr^{-1})	Field growing of vegetables (kg P_2O_5 ha^{-1} yr^{-1})	Viticulture (kg P_2O_5 ha^{-1} yr^{-1})
Input	33.5	30.3	11.4
Inorganic fertilizers	16.7	18.9	-
Manure	11.4	11.4	11.4
Organic products (compost)	4.2	-	-
Atmospheric deposition	-	-	-
Seeds and planting material	1.2	-	-
Outputs	41.4	42.7	3.8
Total harvested crops and forage	41.4	42.7	3.8
Balance (input minus output)	-7.9	-12.4	7.6

For field growing of vegetables, the phosphate balance showed a negative value of -12 kg ha^{-1}, again due to the high level of plant-available phosphate in the soil (260-400 mg kg^{-1} P_2O_5; Labor Pottmann, 2001). The main phosphate inputs were inorganic fertilizers (63% of total inputs) and manure (37% of total inputs).

The phosphorus balance in viticulture showed a small surplus of +8 kg ha^{-1}. The average available soil phosphate contents of vineyards ranged between 110 and >400 mg kg^{-1} (Wr. LWK, 2001), so that, following the guidelines (BMLF, 2000), it was assumed that no phosphate fertilization was given. The high levels of phosphate and also potassium in Vienna's agricultural soils come from ample fertilization in the last decades, a practice, which is now followed by a more moderate fertilization regime.

For other European countries, agricultural phosphorus balances, calculated by the soil surface balance method, yielded surpluses between 20 and 88 kg P_2O_5 ha^{-1} (Isermann, 1994). Arable farms typically show phosphate balances of around 20 kg ha^{-1}, whereas the annual surpluses of animal producing farms range from 29 to 95 kg ha^{-1} (data based on representative supply/withdrawal balances; Isermann, 1994). The phosphorus balances of organic farms range from -13 to +8.5 kg P_2O_5 ha^{-1} at farmgate level (Kaffka & Koepf, 1989; Hege & Weigelt, 1991; Wieser et al., 1996).

Potassium balances

In arable farming, the K_2O balance showed a small surplus of +5 kg ha^{-1} (table 3). As the available K_2O content in soils (measured using the calcium-acetate-lactate method) of all three farming types in Vienna was between 140 and 400 mg kg^{-1} on average (Anonymous, 1994; Labor Pottmann, 2001; Wr. LWK, 2001), the level of potassium fertilization according to the guidelines was low. The main potassium inputs were by inorganic fertilizers (55% of the total inputs) and manure (34% of total inputs), whereas compost played a minor role (8% of total inputs). Atmospheric deposition accounted for 1.6% of the total inputs.

For field cropping of vegetables, the K_2O balance showed a surplus of +27 kg ha^{-1}. 89% of the K_2O inputs were inorganic fertilizers.

Table 3 **Potassium balance of arable farming, field growing of vegetables, and viticulture in Vienna (kg K_2O ha^{-1})**

	Arable farming (kg K_2O ha^{-1} yr^{-1})	Field growing of vegetables (kg K_2O ha^{-1} yr^{-1})	Viticulture (kg K_2O ha^{-1} yr^{-1})
Inputs	62.4	195.3	23.2
Inorganic fertilizers	34.4	173.5	1.4
Manure	21.1	21.1	21.1
Organic products (compost)	5.4	-	-
Atmospheric deposition	0.7	0.7	0.7
Seeds and planting material	0.8	-	-
Outputs	57.6	168.1	16.5
Total harvested crops and forage	57.6	168.1	16.5
Balance (inputs minus outputs)	4.8	27.2	6.7

The potassium balance in viticulture showed a small surplus of +7 kg ha^{-1}.

The potassium balances of arable farms typically show surpluses of 50 kg ha^{-1}. Animal producing farms usually have potassium surpluses of 68 to 124 kg ha^{-1}, depending on livestock density (data based on representative supply/withdrawal balances; Isermann, 1994). For organic farms, including farms with livestock, potassium balances at farmgate level ranging from –6 kg ha^{-1} to +19 kg ha^{-1} were recorded (Kaffka & Koepf, 1989; Hege & Weigelt, 1991; Wieser et al., 1996).

Isermann and Isermann (1994) calculated maximum tolerable nutrient budget surpluses for a sustainable agriculture. For arable farming they called for a maximum nitrogen surplus of 30 kg ha^{-1}, for a phosphorus balance of ± 0 and for a potassium balance ≥ 0.

Amount of organic fertilizers

Animal manure

In the year 1998 the livestock in Vienna included 82 bovines, 962 pigs, 464 sheep and goats, 1136 chickens, broilers and other poultry, and 1072 horses (ÖSTAT, 1999). For animals living shorter than one year, the above numbers are numbers of stable places for such animals. The average livestock number per hectare of fertilized agricultural area was 0.15 large animal units. This livestock excretes 67 t N, 34 t P_2O_5 and 61 t K_2O per year in manures.

Compost

In 1999 a total of 39.700 t compost was produced in Vienna. The largest compost producer was the municipal department 48 (department of waste disposal and street cleansing) producing 31,048 t compost from separately collected yard trimmings and organic household waste. Approximately, 6,000 t compost were produced from yard trimmings by gardening and landscape gardening enterprises. The municipal department 42 (city gardens) produced 1,659 t compost. Last but not least, the organic farmers produced around 70 t compost.

The compost produced in Vienna is used in agriculture, in gardening, and in landscape gardening (figure 1). Approximately two thirds (27,200 t) of the compost were used within the borders of Vienna, and one third (13,000 t) was "exported" to Lower Austria, the province which surrounds Vienna. In Vienna, 4,450 t were used in agriculture and 22,750 t in other fields, mainly in gardening and landscape gardening (both by the municipal department 42, by private enterprises, and by home gardeners).

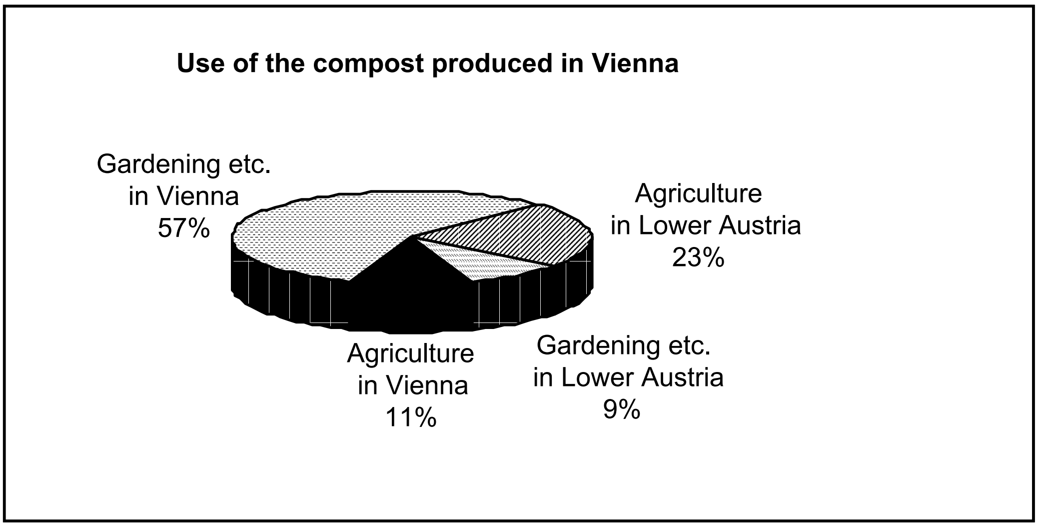

Figure 1 Use of the compost produced in Vienna (reference year 1999)

Conclusion

The agriculture in Vienna showed balance surpluses for nitrogen. The nitrogen surplus was 40 kg ha^{-1} yr^{-1} for arable farming. Viticulture and field cropping of vegetables showed higher surpluses (+52 and +71 kg ha^{-1}, respectively) due to low output in viticulture and to the intensive cultivation in vegetable growing. The phosphorus balances were more or less even. The same was true for the potassium balances except for vegetable growing, which showed a potassium surplus of 27 kg ha^{-1}. However, these are minimum values, assuming that all farmers follow the fertilization guidelines.

Presently, organic fertilizers make up only a small percentage of the fertilizers used. Due to the low livestock density, only a small portion of the nutrient requirements can be supplied through manure. Compost as organic fertilizer and nutrient source is available, but it is used by the farmers only to a small extent. Compost might be a suitable substitute for a portion of the mineral fertilizers used today.

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Improving the nutrient balance of Vienna's agriculture through compost use – a scenario

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Abstract

Today the major part of the arable area in Vienna is managed in the "conventional" way using mineral fertilizers. A sustainable, environmentally beneficial development calls for leveling of nutrient balances and replacing mineral fertilizers, which exploit non-renewable resources and demand high energy inputs, by locally available organic fertilizers. The amounts of nitrogen, phosphate and potassium, which are presently supplied by mineral fertilizers in Vienna and which could be replaced by compost were calculated on the basis of nutrient balances. A survey of the amounts of organic fertilizers which are available in Vienna showed that 40,000 t of compost (fresh matter) are produced annually in Vienna. It was assumed that 15% of total nitrogen in compost would become plant available over a 3-year period. The calculations revealed that approximately one quarter of the mineral N-, P- and K-fertilizers used presently in Vienna could be replaced by an amount of 18,000 t compost. The costs for compost fertilization are 30.5 Euro per hectare higher than the costs for mineral fertilization of the equivalent amounts of nitrogen, phosphate, and potassium. In this calculation the additional benefits of compost use such as improved soil structure, nutrient, and water holding capacity of the soil are not included. Regarding organic farming, the price per kg N in compost is in the lower part of the price range for organic N fertilizers allowed for use in organic farming. Further calculations showed that the available amount of certified compost (according to Council Regulation (EEC) No. 2092/91 on organic agriculture) would be sufficient to support the conversion of 1,500 ha of stockless arable land to organic farming. Compost use would make it possible to multiply the organically managed farmland area in Vienna by four.

Introduction

The production of mineral fertilizers is not sustainable, as it exploits non-renewable resources and demands high energy inputs. World reserves of inorganic rock phosphate are limited and are expected to run out in this century (Anonymous, 1976) or in 500 years at the latest (Finck, 1992). The production of mineral fertilizer consumes 35-42 MJ per kg N for nitrogen fertilizer, 12-19 MJ per kg P for phosphate fertilizer, and 5 MJ per kg K for potassium fertilizer (Diez et al., 1993). The energy inputs are usually provided by fossil fuel enhancing global warming. A sustainable development calls for the use of locally available nutrient sources and for local nutrient recycling. In Vienna, around 40,000 t of biowaste compost are produced per year. The largest part of this compost is a suitable and certified organic fertilizer for agriculture. Unfortunately, the compost is used by farmers only to a small extent, because stockless farms often do not have a spreader which is suitable for compost application. Other reasons are the costs of compost spreading and the lack of awareness of the role of humus for soil fertility and soil structure.

The aim of this scenario was to estimate which amounts of mineral fertilizers could be replaced by compost, to calculate the nutrient costs and the costs of application of compost, and to compare them with other fertilizers, both for 'conventional' and organic farming.

Materials and Methods

On the basis of the nutrient balances calculated by Erhart et al. (2002; in the same volume), an estimate was made as to how much of nutrients which are presently supplied in the form of mineral fertilizers could be replaced by compost. It was presumed that balance surpluses should be minimized, and that the amount of the surpluses should not be replaced. Therefore, the nutrient amount to be replaced is calculated as follows:

Amount to be replaced = amount of nutrients applied as mineral fertilizer today — amount of the balance surplus

Biowaste compost is a compound organic fertilizer. The average nutrient contents of the biowaste and yard trimmings composts produced in Vienna are 1.4% N_{tot}, 0.7% P_2O_{5tot} and 0.9% K_2O_{tot} (on a dry matter basis; Amlinger, 1997; Rogalski, 2000). Therefore, nutrients can be substituted only in that ratio and the nutrient with the smallest need for replacement limits the amount of compost to be used.

The amounts of compost which are available in Vienna were assessed by Erhart et al. (2002; in the same volume). The livestock density was calculated from the number of livestock kept in Vienna (ÖSTAT, 1999) using the calculation factors for Austrian large animal units (Galler, 1999). The average costs for mineral fertilizers were obtained from a market overview prepared by the NÖ-LWK (2000). Costs for mineral fertilizer applications were calculated from guide prices published by ÖKL (1998). The price for bio-waste compost was obtained from Vienna's largest compost producer, the municipal department 48. The costs for compost application were taken from a detailed model calculation for several farms (Rogalski, 2000). The prices for organic nitrogen fertilizers used in organic farming were collected from producers, importers, and traders of such products.

Results and discussion

The nitrogen balance for arable farming in Vienna for 1998 shows an average surplus of 40 kg ha^{-1}. For phosphate the balance is slightly negative with – 8 kg ha^{-1} and the potassium balance shows a small surplus of 5 kg ha^{-1} (Erhart et al., 2001). The largest inputs for all three main nutrients are mineral fertilizers. For arable farming, the input of mineral fertilizer amounts to 407 t N, 75 t P_2O_5, and 154 t K_2O for the total area of arable land in Vienna. These amounts correspond to 90.7 kg ha^{-1} N, 16.7 kg ha^{-1} P_2O_5, and 34.4 kg ha^{-1} K_2O. Arable soils in Vienna are well supplied with phosphate and potassium, so the fertilizer input of P_2O_5 and K_2O is rather low. The present situation of arable farming is summarized in table 1.

Table 1 Nutrient balances of arable farming in Vienna (t yr^{-1} for the total arable area of 4,487 ha; reference year 1998)

	N (t yr^{-1})	P_2O_5 (t yr^{-1})	K_2O (t yr^{-1})
Inputs	618	150	280
Inorganic fertilizers	407	75	154
Manure	52	51	95
Organic products (compost)	37	19	24
Atmospheric deposition	81		3
Biological nitrogen fixation	28		
Seeds and planting material	13	5	3
Outputs	437	186	258
Total harvested crops and forage	437	186	258
Balance (inputs minus outputs)	181	-36	21

Local nutrient sources in Vienna include animal manure, sewage sludge, and compost from bio-waste and yard trimmings. Intensifying organic fertilization by using manure is not possible on a large scale. In the eastern part of Austria, including Vienna, animal husbandry plays a minor role compared with arable farming. The average livestock number per hectare of fertilized agricultural area is 0.15 large animal unit in Vienna. All of the manure produced by these animals is included in the calculations for the nutrient balances, so that there is no more additional manure available in Vienna.

The application of sewage sludge on agricultural land is not allowed in Vienna.

The third local nutrient source is compost from bio-waste and yard trimmings. A total of approx. 40,000 t of compost (fresh matter) is produced annually in Vienna by the municipality and by private enterprises. In 1999, two thirds of the compost were used within the borders of Vienna, 4,450 t of which in agriculture and 22,750 t in other fields, mainly in gardening and landscape gardening. One third was "exported" to Lower Austria, the province which surrounds Vienna.

Grouped according to compost quality, 9,000 of the 40,000 t compost were certified top quality, suitable for use in organic farming (according to Council Regulation (EEC) No. 2092/91 „organic agriculture"). 18,000 t were certified high quality suitable for use in agriculture (class I according to ÖNORM S2200, 1993). The quality of the remaining 13,000 t compost was not necessarily inferior, but these compost lots were either not certified or no information could be obtained on the quality.

The total costs for mineral nitrogen-, phosphate- and potassium fertilizers for the whole "conventional" arable area come to €47,377.00 (table 2).

Table 2 Calculation of the total costs for mineral N-, P- and K- fertilizers for 'conventional' arable farming in Vienna (NÖ-LWK, 2000)

	Present input of mineral fertilizers	Price per ton pure nutrient (Euro)	Price of the total amounts of mineral fertilizers (Euro)
N (t)	407	581.00	236,623.00
P_2O_5 (t)	75	581.00	43,604.00
K_2O (t)	154	436.00	67,150.00
Total			347,377.00

As the nitrogen and potassium balances show surpluses, the present input should not be replaced in total. A further restriction originates from the nutrient ratio of compost. The average nutrient contents of the biowaste and yard trimmings composts produced in Vienna are 1.4% N_{tot}, 0.7% P_2O_{5tot}, and 0.9% K_2O_{tot} (on a dry matter basis; Amlinger, 1997; Rogalski, 2000). The nutrient ratio for the Viennese compost is 1: 0.5 : 0.64.

On a fairly long-term basis the phosphorus and potassium contents of compost are as available as P and K in mineral fertilizers (Gutser, 1996), so the total contents of these nutrients are used for the calculations. Of the total nitrogen content in compost, approximately 15% become plant-available in the first three years after application (Gutser, 1996).

Table 3 presents the calculation of the amounts of nutrients to be supplied by compost. For the total arable land in Vienna, 226 t nitrogen, 75 t P_2O_5, and 133 t K_2O, which are presently supplied by mineral fertilizers, might be supplied by compost.

Table 3 Calculation of the amounts of nutrients to be replaced by compost (for arable farming)

	Present input of mineral fertilizers	Balance	Amount of nutrients to be supplied by compost
N (t)	407	+181	226
P_2O_5 (t)	75	-36 [a)]	75
K_2O (t)	154	+21	133

[a)] The balance deficit is not taken into account for the amount of nutrients to be supplied by compost because of the good nutrient supply of the soil.

The amount of compost for which it would be necessary to substitute for the mineral fertilizers is calculated from the nutrient loads to be replaced (table 3) and the nutrient ratio in Vienna's biowaste and yard trimmings compost. Following this calculation, 18,000 t of compost (fresh matter) would replace all of the phosphate fertilizers (75 t P_2O_5), 96 t K_2O, and 23 t N in mineral fertilizers.

The average costs for mineral fertilizers amount to 581.00 Euro per ton N, 581.00 Euro per ton P_2O_5 and 436.00 Euro per ton K_2O (NÖ-LWK, 2000).

Table 4 Calculation of the costs of the mineral fertilizer, which would be replaced (by arable farming)

	Price per ton pure nutrient (Euro)	Nutrient amounts which could be replaced by compost (t)	Price of the amounts, which could be replaced by compost (Euro)
N	581.00	23	13,372.00
P_2O_5	581.00	75	43,604.00
K_2O	436.00	96	41,860.00
Total			98,836.00

The fertilizer costs for the mineral fertilizer, which could be replaced, amount to 98,836.- Euro. This is 28% of the total fertilizer costs for arable farming. These costs are incurred on the area of arable land which is presently cultivated the 'conventional' way, i.e. approximately 4,000 ha. On a per hectare basis, the costs for the mineral fertilizers which could be replaced amount to €24.7 ha^{-1}.

The average costs for the application of mineral fertilizers, which can be replaced by compost amount to 2.5 Euro ha^{-1} (ÖKL, 1998). In all, the costs for mineral fertilization, which could be replaced, including fertilizers and application costs, are 27.2 Euro per hectare.

The above-mentioned amounts of fertilizers would be replaced by approximately 18,000 t compost (fresh matter), e.i. 5 t per hectare (for 4000 ha). The costs for biowaste compost in Vienna are €6.9 per ton including delivery to the field, resulting in costs of €34.5 per hectare. Compost spreading (including the costs for the transport in the fields and for loading) costs €23.3 per hectare on average (Rogalski, 2000). Altogether, the costs for compost fertilization including compost and application costs are €57.8 per hectare.

The difference between mineral and compost fertilization amounts to €30.5 per hectare. This comparison includes only phosphate, potassium, and the short-term available nitrogen (15% of total nitrogen). Compost, however, is a multifunctional fertilizer. In addition to the main nutrients, compost provides magnesium, calcium, and trace nutrients (Vogtmann et al., 1993). A major part of the rest of total nitrogen, which was not included in the calculation, can be expected to become available on the long term. Compost fertilization increases the humus content of the soil, improving cation exchange capacity; it improves soil structure and the water holding capacity of the soil. In the rather dry climate of the eastern part of Austria (annual precipitation 300–550 mm), the water holding capacity often has a greater impact on yield than soil nutrient contents. Both "conventional" and organic farmers benefit from these advantages when using compost. Summing up these benefits, the price difference of €30.5 per hectare is likely more than equalized.

In "conventional" arable farming, compost is used primarily for phosphorus and potassium fertilization. Therefore, compost is applied to crops with moderate nitrogen requirements.

For vegetable growing, the nutrient balance shows a nitrogen surplus of 71 kg ha^{-1}. The phosphate balance comes to –12 kg ha^{-1}, and the potassium balance to +27 kg ha^{-1}. The inputs of inorganic phosphorus fertilizer total 19 kg ha^{-1}, potassium fertilizers come up to 174 kg ha^{-1}. Compost can be used in field growing of vegetables for phosphorus and potassium fertilization and soil improvement. As compost does not provide enough available nitrogen for most vegetable crops, the nitrogen requirements of the vegetables can be met with additional mineral fertilizer. Virtually no mineral phosphate and potassium fertilizer is used in viticulture due to the high level of phosphate and potassium in vineyard soils. Compost use in vineyards can be recommended for improving soil structure and erosion control (Rasp, 1994) in vineyards, where the K_2O and P_2O_5 supply is not too high.

The amount of 18,000 t compost which would be necessary for the replacing of the mineral fertilizers is available in Vienna. It appears feasible to cut the exports to Lower Austria, which would additionally be favourable regarding the environmental aspect of transport, and to shift some amounts from landscape gardening to agriculture.

For the organic farmers who do not use mineral nitrogen fertilizers compost is also significant as a source of nitrogen. Most organic farms in Vienna are stockless arable farms. Purchasing manure from other organic farms is allowed in organic farming (according to Council Regulation (EEC) No. 2092/91 "organic agriculture"), but as livestock density is low in Vienna and its surroundings, the possibilities of purchasing manure are limited. Various commercial organic fertilizers like rape seed cake, coarse rape seed meal, vinasse, horn meal and horn chippings are also allowed for use in organic farming, if the permission of the control agency is obtained, but they are rarely used in practice. The price per kg nitrogen in this commercial organic fertilizers varies from €4.5 to €16.7. All of those are slow-release fertilizers. They contain nitrogen in an organically bound form, which is slowly mineralized to become plant-available. Therefore the yield level with these fertilizers is 10–20% lower than mineral fertilizers (Söllinger, 1999). Spreading costs for the abovementioned commercial organic fertilizers are calculated with €15.2 per hectare.

In compost, around 15% of the total nitrogen content become plant-available during the first three years after application (Gutser, 1996). The price per kg plant-available nitrogen from compost amounts to €5.5. Compost spreading costs €23.3 per hectare.

However, as already mentioned in the "conventional agriculture" section, compost provides a lot of benefits beyond short-term nitrogen supply, such as supply of other nutrients and humus, long-term nitrogen supply, and improving of soil chemical and physical characteristics.

In organic farming practice, usual compost rates are 5–7 t ha^{-1} (on a fresh matter basis), corresponding to 40–60 kg N_{tot} ha^{-1}. The main portion of the nitrogen requirements is supplied by leguminous crops. In 1999, 9,000 t of certified compost suitable for organic farming (according to Council Regulation (EEC) No. 2092/91 "organic agriculture") were available in Vienna. Presently, organic farmers use 1,500 t of compost per year in Vienna.

The remaining 7,500 t of certified compost, complemented by nitrogen-fixing leguminous crops, would be sufficient for additional 1,500 ha of organically managed farmland, enabling a changeover of this area to organic farming. Presently, the total area of organic farms in Vienna is 500 ha. Compost use would make it possible to multiply the organically managed farmland area.

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Nutrient utilization with and without recycling within farming systems

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Abstract

Nutrient balances are used as a measure of nutrient utilization. It is, however, difficult to compare the nutrient utilization between farms, especially if their production systems are different. New analytical tools and methods of interpreting nutrient utilization based on nutrient balances are introduced.

Nutrients are divided into primary nutrients (f, any external nutrient input into primary production) and secondary nutrients (m, any internal nutrient input into primary production). Primary production, Y, is a result of primary and secondary nutrients: $Y = p(f+m)$ where p = utilization rate of nutrients. The definition of utilization rate of nutrients is the same as that of surface balance. Since surface balance does not provide any information about recycling nutrients, the term circulation factor ($e = (f+m)/f$) is introduced.

Finally, two new tools of measuring nutrient utilization have been introduced. These are primary production balance (N) and internal gate balance (I). Primary production balance ($N = p*e$) indicates the amount of primary production per unit of primary nutrient in any given system. All food production is based on primary production. Primary production can be used directly by humans or converted into animal products. The primary production balance is independent of usage of primary production and comparison between any farm independent of production type is possible.

Unlike farm gate balance (G), the internal gate balance ($I = N * H$, where H is cattle balance) is also independent of the origin and quality of nutrients. It indicates the nutrient utilization within any given system. It is also not sensitive to the production system.

Introduction

Nutrient balance is used as a measure of nutrient utilization. The most used nutrient balances are:

CATTLE BALANCE (H)	=	ANIMAL PRODUCTS / FEED
SURFACE BALANCE (S)	=	HARVESTED YIELD / NUTRIENT INPUT
FARM GATE BALANCE (G)	=	OUTPUT / INPUT

There are, however, some difficulties in comparing nutrient utilization between farms, especially if their production type is different. According to Myrbeck (1999), the farms should be divided into an animal production part and a plant production part. This would increase the usefulness of nutrient balance as an instrument for evaluating operations at farm level and for comparing nutrient utilization between different farming systems. In this paper I introduce some analytical tools and methods of interpreting nutrient utilization based on nutrient balances. Some numerical examples are given to elucidate the ideas. If the ten hypothetical farms listed in Table 1 were ranked from the best to the worst, various answers could be given.

List of symbols (new tools **bold**):

Balances:

G, farm gate balance = output/input

H, cattle balance = animal products/feed

S, surface balance = harvested yield/nutrient input

N, primary production balance (N = p*e)

I, internal gate balance (I = H*N)

Inputs & outputs:

B, purchased feed

F, purchased fertilizer

M, manure

P, total nutrient input (into primary production)

Y, yield (harvested crop, primary production)

A, animal production (secondary production)

Additional terms:

a, utilization rate of feed (a=A/(Y+B))

p, utilization rate of nutrients (equal to surface balance, p = Y/(f+m)

f, primary nutrient (external nutrient input into primary production)

m, secondary nutrient (internal nutrient input, i.e. recycling nutrient)

e, circulation factor (e = (f+m)/f)

y, relative yield (y = Y/f)

Table 1 Nutrient utilization on ten hypothetical farms

	INPUTS		OUTPUTS			BALANCES		
	Fertilizer (F)	Feed (B)	Manure (M)	Crop (Y)	Animal (A)	Cattle (H)	Surface (S)	Farm gate (G)
Farm								
1	100	-	-	80	-	-	0.8	0.8
2	-	80	(64)	-	16	0.2	-	0.2
3	100	-	64	80	16	0.2	0.49	0.16
4	100	-	-	50	-	-	0.5	0.5
5	100	-	40	50	10	0.2	0.36	0.1
6	50	50	80	50	20	0.2	0.38	0.2
7	-	100	118	50	32	0.21	0.42	0.32
8	100	-	90	100	10	0.1	0.53	0.1
9	100	-	120	150	30	0.2	0.68	0.3
10	100	-	153	170	17	0.1	0.67	0.17

Figures are given without any units (i.e. the figures indicate amounts of nutrients and are commensurable). Note: If both crop and animal products are produced only animal products are sold;crop is always used to feed the animals on the farm! Please rank the farms from the best to the worst!

Primary production, secondary production - primary nutrients, secondary nutrients

Farms 1-3 form a special group. Farm 1 specializes in crop production; only crop products are sold without any recycling of nutrients. Farm 2 specializes in animal production with no crop production. Therefore, the surface balance cannot be determined and manure is not used for anything (it is neither sold nor used on the farm). Farm 3 integrates the productions of Farms 1 and 2.

As we can see, the farm gate balance is better on Farms 1 and 2 compared to Farm 3, even when the inputs and outputs on Farm 3 are equal to those on Farms 1 and 2 together. It is obvious that the farm gate balance is not a commensurable indicator of nutrient utilization.

The following equation is valid for Farms 1 and 2:

(1) Y = pF, where Y = primary production, ***p = utilization rate of nutrients***, F = purchased fertilizer (i.e. nutrient input)

(2) A = aY, where A = secondary production (animal production), a = utilization rate of feed

However, the animal production (secondary production) system produces manure (M), which can be recycled in the system. The amount of manure is (theoretically):

M = Y - A

On Farm (3), yield (Y) was obtained not only because of nutrient input (F) but also due to additional manure nutrient input (M = Y-A). To separate these two nutrient inputs, any external nutrient input into the primary production is called ***primary nutrient (f)*** and any internal nutrient input (i.e. recycling nutrient*)* into the primary production ***secondary nutrient (m).*** Hence, the total amount of nutrients available, P, (i.e. nutrient input on the field) is:

$P = f + m$

which gives the final equation for Farm 3:
(3) $Y = p(f + m)$

Both sides of the equation can be divided by f as follows:
(3) $y = p(f + m)/f$, where $y = Y/f$ (relative yield).

The term $(f + m)/f$ is designated as ***circulation factor (e) and equation y = p*e as primary nutrient balance (N).***

Comparison between Farms 1 and 3 shows the difference in nutrient utilization:
(1) $y = p$, *yield is dependent only on the utilization rate of nutrients (p) in any system without recycling*

(3) $y = p*e$, *yield is dependent on the utilization rate of nutrients (p) and the circulation factor (e) in any system with recycling*

Circulation factor, e = (f+m)/f

Definition: the circulation factor (e) indicates how much recycled nutrients (= secondary nutrients) are utilized in the primary production of a farm.

Value $e = 1.0$ indicates no circulation, values higher than 1.0 indicate circulation. As we can see, on the crop farm without secondary production the value of the circulation factor is always 1. If manure is produced on the farm, the circulation factor is always higher than 1. In theory there is no upper limit. In any natural ecosystem (in practice closed systems) very high values of e can be found ($e > 10$), but in agricultural ecosystems values higher than 2 are unlikely.

There are no problems in calculating circulation factors for the systems where only fertilizers are purchased. In these systems fertilizers equal the amount of primary nutrients (f), and manure produced on the farm equals the amount of secondary nutrients (m).

Whenever feed is purchased into the farm it is more difficult to calculate the primary and secondary nutrients. By definition feed itself is not a primary nutrient since it is not used for primary production. However, any manure produced from purchased feed is primary nutrient. On the other hand, all the manure-originated crop produced on the farm is secondary nutrient. Farms 6 and 7 purchase some feed (Table 1). The primary nutrients on Farm 6 comprise 50 units from fertilizers and 40 units from purchased feed (10 units are sold as secondary products and never reach the primary production system on the farm). Secondary nutrients comprise 40 units from crop produced on the farm (10 units are sold as secondary products).

The circulation factor for Farm 6 is: $e = (50 + 40 + 40)/(50 + 40) \cong 1.44$

According to the same principle the circulation for Farm 7 is: $e \cong (0 + 79 + 39)/(0 + 79) \cong 1.49$

Utilization rate of nutrients, p

Definition: the utilization rate of nutrients (p) indicates the proportion of nutrients taken up by crop and harvested in the primary production.

In fact, the definition of p is the same as that of the surface balance (S), which means that they are equal. Most often p varies between 0 and 1, but values higher than 1 are possible. If p is higher than 1, nutrients are taken from the soil, either from the organic (decomposition of organic material) or inorganic pool (weathering of minerals).

The utilization rate does not give any direct information about recycling. Farms 1 and 4 have the highest utilization rates (surface balance) even in the absence of recycling .

Primary production balance, N = p*e

Definition: the primary production balance shows how much primary production is produced per unit of primary nutrients in any given system.

All food production is based on primary production. Only primary products can be converted into food, including animal products. From the ecological point of view animal production is not production at all, it is only one way of consuming primary production (another choice is to use primary production directly by humans). That is why the primary production balance completes the picture of nutrient utilization.

The final efficiency of nutrient utilization in agriculture is determined by two components, utilization rate of nutrients and circulation factor. There is still another choice to be made, either to use the primary production by humans or to process it into animal products. Some primary products are not, however, suitable for human consumption and in such instances there is no real choice available. As long as there is a real choice between crop production and animal production we have to keep in mind that crop production always needs less resources and has less negative environmental impacts than the same amount (energy or nutrients) of animal products. In case there is no recycling between these two processes, the rate of converting primary products into secondary products varies widely between 0.1 and 0.5. These conversion rates indicate roughly the need of resources and environmental impacts in the secondary production compared to the primary production, i.e. 5 to 10-fold the amount of crop products.

The only way of reducing the need of resources and cutting the environmental impacts in secondary production (and in the whole food production process) is to integrate these two processes.

The maximum value in the long run for the primary production balance in any system without recycling is 1.0. Values higher than 1.0 are possible only with recycling, i.e. crop production is integrated with animal production. Another integration partner to crop production could be the community. Please note that the circulation factor has no upper limit!

Primary production balance vs. other balances

The weakness of the farm gate balance is easy to understand either with Farms 1 – 3 or Farms 5 and 6. Farms 5 and 6 are identical in terms of quantity but not quality of inputs. On Farm 5 the inputs comprise 100 units of fertilizers (primary nutrients) and on Farm 6 50 units of fertilizers and 50 units of feed (equals 40 units of primary nutrients in crop production). This is the main reason why the traditional farm gate balance is not a commensurable indicator of nutrient utilization.

If only primary nutrients are input, all the primary nutrients are used for primary production, all the primary production is used to feed the animals and only animal products are sold, the equation would be:
Cattle balance * Primary production balance = Farm gate balance (H * N = G)
But as soon as any of these conditions is not valid, H * n results in a value different from G. However, the primary production balance indicates in any condition how much primary production is produced in any given system by one unit of primary nutrients. Cattle balance is analogous to primary production balance; it shows how much secondary production is produced in any given system by one unit of primary production. Thus, primary production balance multiplied by cattle balance indicates the utilization of nutrients within any given system. This new indicator can be called internal gate balance (I):

I = N * H

Comparing different farms with new tools

Table 2 Nutrient utilization on ten hypothetical farms.

	INPUTS		OUTPUTS			BALANCES					
Farm	Fertil (P)	Feed (B)	Manure (M)	Crop (Y)	Animal (A)	Cattle (H)	Surface (p) (S)	Farm gate (G)	Circulation Primary factor e =(P+M)/P e =(f+m)/f	Internal Production balance N=p*e	Gate balance (I=N*H)
1	100	-	-	80	-	-	0.8	0.8	1.0		0.8
2	-	80	(64)	-	16	0.2	-	0.2	-		- -
3	100	-	64	80	16	0.2	0.49	0.16	1.64	0.8	0.16
4	100	-	-	50	-	-	0.5	0.5	1.0		0.5
5	100	-	40	50	10	0.2	0.36	0.1	1.4	0.5	0.1
6	50	50	80	50	20	0.2	0.38	0.2	1.44	0.56	0.11
7	-	100	118	50	32	0.21	0.42	0.32	1.49	0.62	0.13
8	100	-	90	100	10	0.1	0.53	0.1	1.9	1.0	0.1
9	100	-	120	150	30	0.2	0.68	0.3	2.2	1.5	0.3
10	100	-	153	170	17	0.1	0.67	0.17	2.53	1.7	0.17

The figures are given without any units (i.e. figures indicate amounts of nutrients and are commensurable). Note: If both crop and animal products are produced only animal products are sold; crop is always used to feed the animals on the farm! Besides traditional nutrient balances (cattle, surface, and farm gate) new indicators and tools (utilization rate of nutrients (p equal to surface balance, S), circulation factor (e) and primary production balance (N = p*e)) have been introduced. What is the minimum amount of primary nutrients needed to produce 32 units of animal products and which farm is capable of doing it?

Solution with the old nutrient balance method:

Farm 1 has the highest surface balance and Farm 7 has the highest cattle balance. Would it be possible to produce feed on Farm 1 and animal products on Farm 7 with the highest possible utilization rate of nutrients? To produce 32 units of animal products on these two farms, 125 units of primary nutrients are needed.

Solution with the new method:

Primary nutrient balance (N) shows how much yield (feed) can be produced by unit of primary nutrient. The highest value of N is 1.7 on Farm 10, but the cattle balance is very poor on Farm 10, 0.1. The internal gate balance is 1.7 * 0.1 = 0.17, which is the second highest. The highest internal gate balance is on Farm 9, 1.5 * 0.2 = 0.3. Thus, if only primary products were needed, farm 10 is the best choice, but if the final products must be animal products, Farm 9 is the most effective one (about 107 units of primary nutrients are needed to produce 32 units of animal products).

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Sustainable Recycling of Compost Products in Plant Production

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The research project "Sustainable recycling of compost products in plant production" is carried out at the MTT Agrifood Research Finland in 2000-2002 with financing from the Ministry of Agriculture and Forestry and the Ministry of the Environment and in co-operation with the Plant Production Inspection Centre (KTTK), Häme Regional Environment Centre and Agropolis Ltd. There is a two-sided background for this project. First, environmental regulations require increased utilisation and recycling of wastes, thus increasing composting of municipal organic waste. Second, humus resources of soil are continuously depleted by current agricultural practices, leading towards ever weakening physical properties of the soil. This latter process has to come to a standstill or even to come to a turnaround.

The project aims at improving the quality of composts made of municipal biowaste and sewage sludge and tat developing the quality control of composts in co-operation with compost producers and governmental authorities. The most important objective is to study and verify the effects of the use of biowaste and sewage sludge composts in plant production under Finnish conditions. The manure problems in livestock industry may also be decreased by the development of co-composting systems. This project is divided into three sub-projects; 1) Compost quality, 2) Fertilising effects, and 3) Soil improving and environmental effects.
The Compost quality sub-project concentrates on the development of a compost quality control system for composts used in plant production as well as on promoting the production of quality composts for plant production. Observations of composting processes are carried out in co-operation with the composting facilities. Compost maturation piles are sampled at different points of maturation, and maturity indicators (C:N ratio, NH4:NO3 ratio, plant growth tests), heavy metal content and general properties are analysed. Surveillance of selected composting processes is conducted by regular temperature and oxygen measurements in maturation piles. Preliminary results show that poor compost quality requires improved quality control.

The Fertilising effects sub-project aims at producing extensive knowledge of fertilising effects of the composts in plant production. The objective is to improve the utilisation of compost nutrients and to produce better recommendations for the compost use. Composts made of source-separated biowaste, sewage sludge, or forest industrial sludge are provided by co-operative composting facilities, and applied for the establishment of 3-year field experiments on malt barley and forage grass (grass and red clover-grass). Compost application is based on total P content for 2 or 4 years, with supplementary N and K. if necessary. Plant nutrient content in the soil, nutrient uptake, and yield of plants after compost application are determined and compared to NPK fertiliser or farmyard manure compost. Preliminary results indicate that low plant-available nutrient (N, P) contents in composts will require higher application rates of municipal waste composts or supplementary fertilisation.

The Soil improving and environmental effects sub-project studies soil conditioning effects of composts as well as the advantages and disadvantages of compost application to the environment. The aim is also to minimise nutrient leaching when using composts. In the same field experiments as in the fertilising study, the changes in soil physical parameters are measured. Humus content, nutrient release, and heavy metal contents in soil are determined and followed up. Preliminary results suggest that quality control leads to a dual compost product development. One compost product useful as organic soil conditioner, and another compost product to be used as organic fertiliser with a high nutrient value.

Soiler - Centralised local composting

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The beginning

In 1996, a general debate regarding waste disposal commenced at Hvanneyri, particularly as to how the local community could rid itself of organic household waste, including paper and cartons. About 180 people live at Hvanneyri, the University dormitory houses 80 students and is run as a hotel during the summer. From the start, a comprehensive solution was aimed at, namely that no organic waste would have to be carried away.

When several alternatives had been considered, a method called "closed composting" was opted for. This method is well suited to the needs of apartment buildings or communities with common garbage storage where the inhabitants themselves bring the garbage to the container. There are several ways available but all are based on the same principle: an insulated container or barrel and a device to mix the compost. All types are based on a fairly regular feeding of waste. To prevent bad smell, ventilation is provided through the barrel, and, preferably, into a sewer system.

After looking at several models, it was decided to try ALE-trumman, a product of Kompostinnovation, Gothenburg, Sweden, (now: Japan West, yajpnwe@algonet.se). They are offered in different sizes, for 30-120 households. The Hvanneyri Agricultural University purchased the composter and received a grant from public authorities. The composter arrived in January 1997, and was put into service in early February. It was given the name, **MOLDA**, (**SOILER**).

Procedure

Organic waste is collected once every other week and loaded on a pick-up truck. Usually, the inhabitants put their waste in plastic shopping bags that are put out on the pavement to be collected. The waste is then weighed and put into the composter along with supporting material. The amount is usually about 150-250 kilograms. Waste from the University refectory and the hotel is collected continually. The waste is far too soggy for the growth of desirable microorganisms, so supporting material has to be added. The role of the supporting material is to increase the proportion of dry matter and to provide carbon, which is necessary because the waste is usually rich in protein. Hence, without a source of carbon, there is a considerable risk of release of a substantial amount of ammonia. Sawdust or straw are the best support materials but shredded paper can also be used, particularly mixed with other matter. It is essential that, before starting to make compost, regardless of the method used, an ample supply of supporting material is ensured.

The people

In the beginning, the project was presented at an open meeting and in newsletters. A card with instructions about sorting of household waste was distributed along with a garbage-collection calendar. The local people have been very positive to ward the project. There have been no problems with the sorting and storing of the garbage. During the warmest part of the summer, two weeks between collections is close to the tolerable limit, though. Particularly leftovers of fish tend to generate bad smell and attract flies. Quite commonly the inhabitants bring their organic waste to the soiler themselves. It is important that the collection of the garbage is fixed at convenient hours to prevent the garbage from lying on the pavement longer than necessary. Dogs are kept indoors during the collection hours.

Organic waste becomes compost

The waste loses its form and colour very rapidly and is undistinguishable within 1-2 days in the composter, except for bones, of course. Whole fruit and vegetables, particularly oranges and raw potatoes and beets, seem to withstand the process quite well though. The inhabitants are encouraged to slice large pieces. According to some manuals, the appropriate size of chunks is the same that you would put in your mouth when eating. One can assume that the average fermenting time is 1-3 weeks.

Maturation

When the compost is removed from the composter, it is sifted and put into insulated boxes for maturation. The material that is separated from the compost is mostly bones. These are put back into the composter as they are a good source of phosphorus and lime.

The matured compost has been tried as fertilizer in horticulture where it proved to be an excellent fertilizer. This was also the case when it was used for growing trees and windbreaks. It can be spread on uncultivated hills and gravel plains+, as it does not attract birds or vermin.

It should be noted that there is a qualitative difference between the compost from MOLDA and regular compost from gardens. This is due to the fundamental difference of the raw materials.

Operation

The operation of MOLDA has from the start been the responsibility of the Agricultural University. This is still the case, but now the University receives support from the local municipal authorities according to a special contract.

Projects like the MOLDA project have a beginning and need to be followed up. This would be of no use if the local people didn't support the project as they have done at Hvanneyri. Inhabitants and staff have been enthusiastic, and everybody agrees that the sorting of the household waste is no problem at all. The awareness of garbage disposal has increased with the public.

MOLDA does not solve the problems of the world, but for the people at Hvanneyri it has been a step in the right direction.

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