NUTRITIONAL CONSEQUENCES OF USING ORGANIC AGRICULTURAL METHODS IN DEVELOPING COUNTRIES

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Summary

In addition to improved yields, the use of organic methods can benefit the nutritional value of foods in several ways, compared with subsistence agriculture, and in some respects also when compared with the use of high-input conventional farming methods. The recycling of organic matter retards depletion of the soil and ensures that increases

in yield are not offset by mineral deficiencies caused by unbalanced plant nutrition. City populations can use organic products to minimize their intake of pesticide residues and nitrate. Improved nutritional status of crops under low-input conditions can increase the contents of protein and vitamin A, but can also increase the contents of some anti-nutrients. Improved availability of firewood through agroforestry enables thorough cooking to ensure removal of anti-nutrients and full utilization of nutrients. Increased diversity of crops not only provides a more dependable food supply, but also increases the chance for obtaining a full complement of nutrients due to the variability in composition of different staple crops. The increased use of pulses, vegetables and fruit also overcomes shortcomings in the nutritional values of the main staple crops, such as maize and rice. However, to obtain the full benefits from these methods, substantially increased and much more targeted research on the development and use of organic agriculture methods under tropical conditions is necessary, especially in connection with subsistence agriculture.

1. Introduction

1.1. Definitions of Organic Agriculture

Organic agriculture is defined by a set of general principles, which have been endorsed by the International Federation of Organic Agriculture Movements (IFOAM) and other relevant organizations. The principles comprise a “positive list”, explaining what an ideal organic agricultural system should contain.

Some of “The Principle Aims of Organic Production and Processing” are:

- To produce food of high quality in sufficient quantity.
- To interact in a constructive and life-enhancing way with natural systems and cycles.
- To consider the wider social and ecological impact of the organic production and processing system.
- To encourage and enhance biological cycles within the farming system, involving micro-organisms, soil flora and fauna, plants and animals.
- To maintain and increase long-term fertility of soils.
- To maintain the genetic diversity of the production system and its surroundings, including the protection of plant and wildlife habitats.
- To promote the healthy use and proper care of water, water resources and all life therein.
- To create a harmonious balance between crop production and animal husbandry.
- To give all livestock conditions of life with due consideration for the basic aspects of their innate behavior.
- To use, as far as possible, renewable resources in locally organized production systems.
- To progress toward an entire production, processing and distribution chain, which is both socially just and ecologically responsible.

On the other hand, the practical distinction between organic and other cultivation systems are made by rules defined by a certifying organization or department, and they normally have the format of "negative lists", defining what is not allowed on a certified organic farm or other production unit. So the trade-oriented definitions of organic agriculture emphasize the absence of pesticides, synthetic mineral fertilizers, genetically modified organisms and synthetic and antibiotic additives to food and feed. This exclusive, controllable and verifiable view is very relevant for farms that trade most of the agricultural output as certified products, normally at a premium price, which is by far the most common case in developed countries. Here, the primary objective of the rules is to prevent fraud. The promotion of biological cycles and soil fertility are then ensured by simple economic incentives, and of course are supported by education schemes for new organic farmers, since a detailed knowledge of sustainable farm management is necessary for the farmer to obtain sufficient yields to make a profit on a competitive market.

1.2. Organic Agricultural Methods

When focusing on the nutritional consequences of agricultural systems in developing countries, the crops grown for local consumption are the most important ones. Certification is irrelevant for the crops that are consumed by the producers own family, and is not very important for those that are traded locally, but it can still make a great difference to how the crops are grown. The trade rules are often too "schematic" to be of any use in this context.

This is where the use of the concept of "organic agricultural methods" becomes important. "Organic agricultural methods" is a term we use to describe the individual parts of the principle aims of organic agriculture listed above, in particular methods to improve and sustain soil fertility, water resources and renewable resources. The idea is to distinguish between farming systems that use these methods to a greater or smaller extent, rather than only making an "all or nothing" distinction. Actually, decreasing soil fertility is particularly a problem in the poorest areas, where no or little external inputs are used, emphasizing that fulfilling the "trade definition" of organic agriculture is not by itself any guarantee for continued sustainability. We are aware that the methods we describe are by no means unique to organic agriculture, and are in fact important for any kind of environmentally responsible agriculture across the globe, so one could argue for alternative terms such as "good agricultural practice". However, since in this review we want to emphasize the selection of methods that can be used without external input, and are in accordance with the basic principles of organic agriculture, we consider the term "organic agricultural methods" as the best overall description.

The overall purpose of this article is to describe the nutritional consequences in developing countries of the use of organic agriculture methods. So below, we will describe some organic agriculture methods in general terms, to provide a background for the discussion of the nutritional consequences of their use. A more detailed account of the use of the methods in developing countries which we define here as "organic agriculture methods", from the perspectives of extent of use, practical problems and solutions, can be found in other parts of the EOLSS. The actual actions to be taken in order to implement these and other (high-input) methods on the level of rural communities, is covered in *Community-Centred Food-Based Strategies for Alleviating and Preventing Malnutrition*.

The bulk of the article describes the changes in crop composition and utilization with impacts on nutritional value, which is expected to result from the use of organic agriculture methods in the context of subsistence farming. However, the actual data are very limited, since this is an area where only very little research has taken place. It is our hope that by describing some of the potential perspectives of these methods, it will be possible to attract more attention to the area, and thus to enable more rigorous scientific investigations of the actual benefits. In terms of target group, the present paper thus complements the article *Influence of Organic and Conventional Farming Systems on Nutritional Quality of Food*, which describes the differences between certified organic food and high-input, conventionally grown foodstuffs, the two options that are, at least in principle, available to consumers who are not themselves producing their own food, and are the most relevant comparison in developed countries and in relatively affluent regions of developing countries.

So in this context, it is particularly important to distinguish between cash crops and farming for local consumption, and thus between the exclusive ("negative", trade oriented) and the inclusive ("positive", local sustainability oriented) definitions of organic agriculture, because both the limitations and the possibilities are very different. If the nutritional benefits for low-income farmers are as great as we envision, it is very important that they are utilized, primarily through strengthening the research based locally adapted educational efforts. Particular emphasis should be put on those methods that in a given area can improve both yield and nutritional value in a sustainable way, without requiring increased external inputs.

2. Organic Agriculture Methods in Developing Countries

Most of the worlds farmers carry out subsistence farming on much or all the cultivated area. In subsistence farming, the output is consumed within the family or traded locally, and trade on a regulated market is not the primary objective. Subsistence farmers have no incentive to support expensive certification schemes, and for these, by far the most important aspect of organic farming is the first "principle aim", to produce food of high quality in sufficient quantity.

Most traditional farming systems were based on the use of fallow periods to restore soil fertility, and some defined crop rotations to ensure the best use of the plant nutrients liberated after the fallow fields enter the cultivation phase. Normally starting with the most demanding crops, then a few seasons with crops that can grow at lower levels of nutrient availability, and finally the field was abandoned for many years until fertility was sufficiently restored. In areas where the natural ecotype is forest, this is known as the "slash and burn" system. However, as population increases, the fallow period must be shortened, and at some point, the fertility can no more be fully restored from one cycle to the next. When this happens, a downward spiral appears for the overall soil fertility. When yields decline, larger fields must be cultivated to ensure the necessary food supply, and the fallow area declines even faster than before. If the population continues to increase and no external inputs of plant nutrients are provided, the soil is finally so devastated that the natural vegetation is unable to re-establish itself, and food production in the area collapses. A similar sequence of events has happened in the past in some places in many areas of the world, well documented by excavations near the ruins of ancient civilisations. However, today we have less available land and generally higher population densities than ever before, so declining soil fertility is a major problem for most poor, rural populations.

In areas where the farmers can sell their products at sufficiently high prices, they have the option to purchase mineral fertilizers to improve some of the aspects of soil fertility. However, in many places, the economic realities rule out this solution, since the price of farming inputs are higher than the added income they can generate, e.g., due to high transport costs and/or competition from subsidized farming. Here, the farmers must use other ways to maintain and increase long-term fertility of soils. The situation is thus very different for growers of cash crops than for subsistence farmers, and the present article will primarily be concerned with the latter, which are likely to comprise the largest numbers of people, although not the greatest area of farmland.

The primary incentive for subsistence farmers to use organic agriculture methods is increased yield per area unit without the need to purchase fertilizer and pesticides. Only techniques that can provide this have potential for widespread application. Some of the organic agriculture methods that are useful for subsistence farmers, in particular crop diversification, may not affect yield directly, but instead reduce the risks of crop losses due to both physical disasters, such as droughts or storms, and biological ones, diseases or pests. In this context, it must be born in mind that everything else being equal, improvements in productivity of a crop, in particular a widely grown one, also increase the risk of establishment of devastating populations of pests and pathogens.

The principles behind most of the organic agriculture methods are that they simulate the restoring processes that take place during a fallow period. Since they are integrated within several steps of the crop rotation, the restoring periods are both more efficient and more frequent than in simple slash and burn systems. On the other hand, they are generally more labor-demanding than the extensive subsistence farming methods, so the family will only observe an advantage if there is not enough land available. The greatest advantages will be in areas where over-population is combined with under-employment, unfortunately not an unusual combination.

2.1. Plant Residues and Animal Manure

Normally a major fraction of the plant nutrients are contained in the inedible parts of the crop. The recycling of as much as feasible of the organic material produced on a farm is an important method in organic agriculture. The objectives are to provide nutrients for the subsequent crops through mineralization, to retard leaching losses by extending the mineralization period, and to improve soil structure and replenish the nutrient-holding capacity of the soil by nourishing its microbial communities.

These objectives are best fulfilled when as much as possible of the carbon-containing material is returned to the soil. Plant residues that are not needed for use for fodder or fuel should preferably be incorporated into the soil, rather than burnt. In particular, if nitrogen is a limiting factor for plant growth, which is usually the case, except for legumes. If fresh plant material is incorporated, the nutrients will be much faster mineralized and thus available for the crop than if only lignified residues are used. However, if the soil is not continuously covered by growing plants, e.g., if a dry season occurs, in the beginning of a wet season the levels of nutrients such as nitrogen will often exceed the capacity of uptake of small seedlings. In such a situation, the incorporation of relatively nutrient poor plant material, such as straw, can serve to prevent leaching by immobilizing available nitrogen (N), which will later be re-mineralized when the plant residues are finally broken down, at a time when the crop is able to utilize the nutrients. So the type and timing of incorporation of plant residues must be tailored to needs of the crop in question and the local soil and weather conditions to obtain optimal utilization of nutrients. On acid soils, as are common in tropical areas, addition of manure or easily degradable plant material to the soil also increases the availability of phosphorus (P) to plants through competition between organic anions and phosphate anions at ligand exchange sites.

The composting principles often used in temperate organic agriculture comprise the collection, mixing and management of organic material to enhance its conversion into forms that are easily liberate the plant nutrients to the crop where it is used as fertilizer. These methods are not always an advantage under most tropical conditions, since substantial fractions of the nitrogen can easily be lost as ammonia or nitrate during preparation, storage and handling of the material, and since the degradation of organic material in the field is so rapid that the fertilizer value of compost is not much higher than when the material is incorporated directly. Composting is most useful for cases where the collection and storage is an objective of its own, to ensure that the material can be supplied at the optimal time for a crop, or where composting at high temperature is used to decontaminate human or animal waste or diseased plant material, which may otherwise propagate diseases or parasites.

The components of the plant material that are most important for the improvement of soil fertility and structure, are the ones that are the most difficult to degrade. Due to this, the value of plant residues are not greatly diminished if they are eaten by animals, and the manure is then retained in the field, or returned to it, as long as the timing and local conditions ensure against losses due to volatilization and leaching. However, it is very important to ensure that the nutrients are distributed evenly over the field, e.g., by regularly moving pens or stables where animals are kept at night. A substantial part of the available nutrients can be lost through leaching if the animals leave their urine and droppings mostly on a small part of the field, even when the average amount is much less that what the soil can absorb. Of course it is also advantageous that the waste of the human inhabitants of the farm is distributed across the fields in safe ways that ensure full recycling of nutrients without a risk of propagation of parasites and diseases.

If the material is needed as fuel, it is possible to collect a large part of the energy content as bio-gas, by using a variety of small- and medium-scale methods that have been developed for this purpose. They all require some amount of investment, though. Degassed and other liquid organic waste should only be used on actively growing crops on fields with minimal surface runoff, to prevent leaching or wash-out.

Even if the plant residues or dung must be burned to provide fuel, it is still an advantage to return the remaining minerals (P, K, Zn etc.) to the soil, by collecting the ash and spreading it in the field. Much of the minerals are present in ash in water-soluble forms, so the storage of the ash and the timing of the application must be planned to ensure that they are not lost by leaching before the crop is established.

2.2. Catch Crops and Agroforestry

A major aspect of organic agriculture methods is crop rotation. Due to differences in nutrient requirements and root growth characteristics, crops can be selected so they utilize the nutrients released from the residues of the preceding crop, and retard the depletion of water and certain nutrients. Specific catch crops can be established in the crop rotation with the principal objective to take up and later release nutrients that would otherwise be lost. Another dimension of crop rotation is agroforestry, where perennials are grown among shorter-lived crop plants to serve the same purpose, as well as other uses. Both short-term catch crops and perennials may be used for fodder before nutrients are returned to the field as manure, and also can provide material to be harvested for other purposes. So there need not be any definitive distinction between crops and catch crops, and the important aspect is the effort to reduce nutrient losses as much as possible.

Legumes provide nitrogen through fixation from the atmosphere, so legumes are important aspects of any low-input cultivation system. They can be grown as crops in their own right, for fodder or feed, or solely as sources of green manure. While most legumes fix nitrogen, and therefore have high nitrogen contents in their tissues, some species also produce large amounts of tannins and other compounds that make this nitrogen less available for animals or microorganisms. Due to this, the rate of release of nutrients from the plant residue will differ greatly among species, plant parts and maturity of tissue, and often the initial phase of degradation can comprise a net uptake of nitrogen from the soil. Under low-temperature (temperate) conditions this can be an important problem, since the nutrients may be locked up for more than one growth season, but in the tropics it usually just implies that the nutrients will be released a few months later, so the N of a green manure can in some cases be utilized with the same or even greater efficiency as urea when both are incorporated at the start of a growing season. In any case, it is crucial that the timing of the incorporation of the catch crop materials is adjusted to the needs of the crop.

Catch crops are often a good choice in climates where cold or dry seasons limit the periods where crops can be grown. If a catch crop can be established right after the harvest of the main crop, and can grow slowly during the dry or cold season, and be incorporated shortly before the next main crop is planted, nutrient leaching is minimized. The nutrients mineralized during the non-crop period will become available to the main crop when the plant material is fully degraded, and this can often provide substantial amounts, much more than if the soil was left without plant cover for the same period. To optimize the use of catch crops, it is important to consider both the fluctuations of mineralized nutrients (primarily N) that take place in the topsoil over time, and also the vertical component of nutrient leaching, in terms of the movement of the nutrients down through the soil layers before they are lost below the level of the deepest roots. In some cases, a catch crop with fast-growing roots can reach and retrieve nitrogen, which has resided for more than one growth season in medium deep soil layers, unavailable to a shallow rooted main crop. However, if used indiscriminately, catch crops may in some cases harm the crop more than they benefit it: if a deep-rooted catch crop is grown before a deep-rooted main crop, the catch crop can have depleted the subsoil so efficiently that the yield of the main crop is reduced rather than improved. This effect, pre-emptive competition, must be considered, particularly in dry areas, where water removed by the catch crop may be more important than the nutrients it provides. However, in areas where the leaching of nutrients to ground water is an important problem, catch crops will usually be able to provide a positive input of nutrients to the main crop. And in many cases, the catch crop can also provide some other useful product, such as fodder, vegetables or seed, even though the yield may be too low to justify the cultivation on its own. Also, the use of catch crops will usually benefit weed control, at least simply, by competing with weeds during its growth period and thus reducing their seed production. Often more important can be the effect on crop competitiveness due to the altered distribution of nutrients in the soil, compared with a situation where manure or synthetic fertilizer is broadcast at the time of sowing. When the main crop has been sown at the appropriate time after the incorporation of a catch crop, most available nutrients will be situated 10 or more centimeters below the soil surface, just below the seeds of the crop. The crop plants start taking up the nutrients right after germination, but for several days the nutrients are unavailable to the seedlings of the weed plants, which tend to germinate in the upper 0-1 cm of the soil. For cereals and other quickly germinating, relatively large-seeded crops, this advantage allows the crop a head start that in some cases practically eliminates the need for weed control.

When vigorous crops such as cereals are grown, often slow-growing catch crops and/or nitrogen assimilating (leguminous) plant species can be undersown together with the main crop, or later, when the main crop is well established. For the right combinations of main crop, undersown crop and sowing time, the undersown crop does not affect the yield of the main crop, but in particular if it is allowed to keep growing for a period after the main crop, it will improve the performance of the subsequent crop.

Some plant species are especially adapted to poor soils, and have the ability to extract e.g., phosphorus from the soil with greater efficiency than most crops. They can be used either as catch crops or, for plants that need longer periods for establishment, on fallow or non-cultivated land, where they can be harvested for fodder and thus provide animal manure, or the aerial parts can be harvested to directly provide green manure to be transferred to the area where the crops will be grown.

In agroforestry, the catch crops are permanent, usually woody plants, grown so close to the crop plants that they can take up excess nutrients, but repeatedly cut down to a size that does not compete too much with the crop. The cut material can be used for fodder and/or fuel, or directly incorporated into the soil as green manure. Often, the sustained provision of firewood and protection against erosion and wind are equally important as the nutrient recycling. While tree leaves and shoots are usually not very nutritious fodder, the manure can be better for soil fertility improvement than manure from animals fed more easily digestible fodder, since the nitrogen from tannin-containing tree leaves is preferentially retained in the feces, which can be relatively easily collected and used as manure, rather than being excreted (and often lost) with the urine.

A sustainable crop rotation without any catch crops or nutrient input normally requires that the land is left fallow for 5-20 years after two or three cropping seasons, a few more if legumes are included. With optimal use of catch crops, and sowed, managed leys for the fallow period, the fallow (ley) area can be reduced to 30-50 percent of the total farmed area under temperate conditions – also when the leys are grazed. The nutrient mineralization processes in good quality tropical soils are similar to those of temperate soils, except that all processes occur faster, indicating that the proportions needed for sustainability are likely to be similar, but also that here even short periods without plant cover can result in significant nutrient losses. However, for already depleted, poor, tropical soils, where even the natural plant cover is slow to establish during a fallow period, obtaining true sustainability at a reasonable yield level is much more difficult, and can require an initial input of large amounts of good quality organic matter or another source of plant nutrients. But even under conditions where it is unrealistic to ensure impressive short-term improvements of soil fertility on poor soils without external inputs, the methods described here can still serve to retard the widespread degradation seen today. Including improvement of the utilization of mineral fertilizer when it is available, e.g., in connection with short-term aid programs.

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Biographical Sketches

Kirsten Brandt has an MSc in biochemistry, awarded in 1987 from Odense University, Denmark. She also has a Ph.D. in plant chemistry and genetics, awarded in 1991 from the Royal Veterinary and Agricultural University, Denmark. Since then, she has been at the Danish Institute of Agricultural Sciences, Department of Horticulture. In 1998, she was appointed Head of the Research Unit for Food Quality and Natural Products Chemistry (http://www.darcof.dk/).

Her primary research interest is plant secondary metabolites affecting quality of plant products, and in particular the effects on human health, and investigations of interactions between genetics, environment and product quality of plants.

Her research on organic food quality has involved coordinating the research projects "Plant health and quality as influenced by crop management strategies and cultivar choice" (1996-1999) and "Quality in relation to processing, plant health and breeding" (1997-2000) in the first call of the Danish Research Centre for Organic Farming (DARCOF, http://www.agrsci.dk/foejo/DARCOF.html). She now coordinates the DARCOF research project "Organic food and health – a multi-generation animal experiment" (2001-2004).

Her other research and administrative tasks involve coordinating the research network "Health promoting substances in vegetable foods" (2000-2002), funded by the Danish Research Council for Agricultural and Veterinary Sciences, which includes studies of possible health promoting effects of polyacetylenes in carrots. She also coordinates the vegetable part of the project "Content and bioavailability of vitamin A, iron, and zinc in commonly consumed foods in developing countries" (2000-2003), funded by the Danish Research Council for Research in Developing countries, investigating the effects of traditional processing of tropical vegetables on vitamin A utilization.

She was the Danish delegate in the European Commission Committee on Genetic Resources in Agriculture (according to regulation 1467/94), and has been a participant in the EU Concerted Action NEODIET, "Nutritional Enhancement of Plant Foods in Europe", and a participant in the EU RTD project WORMCOPS, "Worm Control in Organic Production Systems for Small Ruminants in Europe: Towards the implementation of non-chemical, sustainable approaches".

Ulla Kidmose has an MSc in food science, awarded in 1989 from The Royal Veterinary and Agricultural University, Copenhagen, Denmark. She has been employed at the Danish Institute of Agricultural Sciences since 1990. Since 2000, she has been enrolled as a Ph.D. student at The Royal Veterinary and Agricultural University, Copenhagen. Her daily work is conducted at the Danish Institute of Agricultural Sciences. The main area of her research is the nutritional quality of plant products, in relation to nutrition and health in humans. Her Ph.D. project is about pro-vitamin A carotenoids in vegetables, and changes in pro-vitamin A carotenoids in relation to home preparation. The Ph.D. project is a part of the project "Content and bioavailability of vitamin A, iron, and zinc in commonly consumed foods in developing countries" (2000-2003), which focuses on micronutrients in different components of the diet in developing countries. The project is funded by the Danish Research Council for Research in Developing countries. She is also involved in projects about plant secondary metabolites in organically grown potatoes and nutritional quality of organic vegetable products directed towards children.