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# Eco-functional Intensification and Food Security: Synergy or Compromise?

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**Abstract**

There is an increased understanding that the challenges of producing enough food and biomass while preserving soil, water and biodiversity necessary for ecosystem services can not be solved by prevalent types of conventional agriculture and that agro-ecological approaches and ecological intensification is fundamental for our future food production. FAO has stated that "Ecosystem services sustain agricultural productivity and resilience" and advocates production intensification through ecosystem management. Terminologies such as agro-ecology and ecological/ eco-functional/sustainable intensification are being proposed for agricultural development, which builds on higher input of knowledge, observation skills and management and improved use of agro-ecological methods. Contrary, increased global demand for food, and non-food biomass has increased the pressure for intensifying land use and increasing crop yields based on conventional inputs, while still aiming at reducing environmental impact. There is a battle of discourse between these approaches in competition for – among others – research and development funding. The examples of improved local food security from introducing agro-ecological and low external input agriculture practices among smallholder farmers are many. However, upscaling remains a challenge and the ability of such eco-functional intensification to feed the increased urban populations in emerging economies remains an open question. A broader view of what is organic and conventional farming is necessary and the use of new understandings from ecology and molecular biology will be needed to create and profit from synergies between preserving and building on eco-systems services and providing increased food and biomass.

**Keywords:** global food security, organic, agroecology, sustainable intensification

## 1. Introduction/Background

There is an increased understanding that the challenges of producing enough food and biomass while preserving soil, water and biodiversity necessary for ecosystem services cannot be solved by prevalent types of conventional agriculture and that agro-ecological approaches and ecological intensification is fundamental for our future food production. FAO has stated that "Ecosystem services sustain agricultural productivity and resilience" and advocates production intensification through ecosystem management. Terminologies such as agro-ecology, ecological, or eco-functional or sustainable intensification are being proposed for agricultural development, which builds on higher input of knowledge, observation skills and management and improved use of agro-ecological methods. Contrary, increased global demand for food, and non-food biomass has increased the pressure for intensifying land use and increasing crop yields based on conventional inputs, while still aiming at reducing environmental impact. There is a battle of discourse between these different approaches in competition for – among others – research and development funding.

The aim of this paper is to assess under which conditions and to what degree organic and agroecological approaches may be valuable pathways for improving food security in short and long term perspectives, respectively.

## 2. The Food Security Challenge: Trends and Competing Discourses

According to FAO there is a need to increase global agricultural output by 60% between 2010 and 2050 and the major part of this increase in agricultural output should come from developing countries, where agricultural biomass production should be doubled over the period (Alexandratos & Bruinsma, 2012). Tilman et al. (2011) found that extrapolating historical relations between per capita GDP and crop demand for feed and food to 2050 would result in a doubling of the need for crop calories and protein compared to 2005. This estimate was based on UN projections of population growth and on assumptions of average GDP per capita growth of app. 2.5% per year with higher rates for developing countries. Tilman et al. (2011) thus considered diet changes as extrinsic to developments of agriculture and population pressure and did not include options for reducing livestock food intake by high income consumers or options for reducing food waste (Smith, 2013). An important part of this challenge is linked to the increasing demand for livestock products and increasing use of crops for non-food purposes such as biofuels. Cassidy et al. (2013) estimated that 36 and 53% of crop yields measured in calories and protein, respectively were used as livestock feed around the year 2000. This proportion is growing and so is the proportion of biofuel crops, where the ethanol production in US and Brazil accounted for 4% of global calorie production in 2010.

Harwey and Pilgrim (2010) analysed the drivers for increased competition for land arising from the combination of increased food needs towards 2050 and increased demand for biomass to replace petrochemical products and concludes that the combined challenges of delivering both increased food and biomass while mitigating agriculture's contribution to climate change and other environmental impacts calls for a "long term political strategy driving forward the shift to a sustainable intensification of land use". Using the data from app. year 2000 in average 6 persons were fed per hectare of cropland which is a combination of yields, losses and feeding crops to livestock (Cassidy et al., 2013). This differs greatly from region to region. Theoretically, by reducing the proportion allocated to livestock feed and biofuels the global average could rise up to between 8-10 persons fed per hectare, with up to 16 person per ha in the US using the current crop yields.

As discussed in Halberg (2009) the food security challenge is aggravated by current non-sustainable trends in terms of undermining agricultural systems' functional integrity and the natural capital necessary for ecosystems services in general. Eco-systems services, which are important for agriculture and for other societal purposes are undermined by some agricultural practices due to wrong use of fertilizers and pesticides and lack of proper soil protection and soil fertility building (Lal, 2009; Nelleman et al., 2009; Beddington et al., 2011; Gomiero et al., 2011). The climate change represents yet another challenge for the improved food security currently and even more so in the perspective of the crop needs towards 2050 (Wheeler & Braun, 2013; Porter et al., 2014). All aspects of food security are potentially affected by climate change, including food access, utilization and price stability. The triple challenge of increasing food and biomass production while adapting to climate change and at the same time reducing the negative impacts on natural capital and environment is addressed under different discourses, which however partly use overlapping terms (Halberg, 2009). The terms and ideas of Ecological (Cassman, 2008; Bommarco et al., 2013; Tittonel, 2014) or eco-functional intensification (Niggli et al., 2008), sustainable intensification (Pretty & Bharucha, 2014; Garnett et al., 2013; Buckwell et al., 2014), climate smart agriculture (Lipper et al., 2014), organic agriculture (Halberg, 2009) and agro-ecology (Wezel, 2009; Altieri et al., 2012) may be seen as different discourses competing for hegemony (Howarth, 2010; Unger, 2012) in terms of defining the "right" development pathway for agriculture and thus gain political and economic support (development funding, research and innovation funding, subsidies, ..).

The term *sustainable intensification* (SI) is defined by FAO (2011) as a productive agriculture that conserves and enhances natural resources. It uses an ecosystem approach that draws on nature's contribution to crop growth and enhances soil organic matter, water flow regulation, pollination and natural predation of pests and applies appropriate external inputs at the right time, in the right amount. This approach according to FAO represents a major shift from the homogeneous model of crop production to knowledge-intensive, often location-specific, farming systems. Garnett et al. (2013) discuss four premises underlying the concept of SI and remarks that while an overall increase in food production is needed it should go hand in hand with reducing food waste and moderating demand for resource intensive livestock food products. Overall food production should be increased while reducing environmental impact and reflecting different balances in different contexts. This is in accordance with Buckwell et al. (2014), who moreover suggest that SI, especially in Europe, is not primarily about the use of more fertilizers, pesticides and machinery applied per hectare, but the development of much more knowledge intensive management including of the ecosystems services on which agriculture relies. They propose "more knowledge per hectare" as a shorthand for SI. While most discourses agree to this goal they differ in the assessment of the necessity of increasing external inputs and the most pertinent ones e.g. fertilisers, pesticides, seeds, ICT, … (Gianess, 2013; Pretty & Bharucha, 2014; Curtis & Halford, 2014).

Bommarco et al. (2013), defines *Ecological intensification* (EI) as an approach to agriculture which aims at integrating ecosystems services from managing biodiversity in crop production systems in order to secure and augment yields with low negative environmental impact (see also Kremen & Miles, 2012). Thus, these approaches differ from the wider definitions of SI and are more in line with the agroecology movement of especially Latin America (Altieri et al., 2012; De Abreu & Bellon, 2013) and with principles of organic agriculture.

*Agroecology* has several meanings as reviewed by Wezel et al. (2009) ranging from a scientific discipline which applies principles from ecology in the study of agricultural systems (a field, a farm, landscape, …) to a comprehensive action oriented and partly normative framework for development of a certain type of farming systems and to a movement of farmers and stakeholders applying these principles for the livelihood improvement of smallholder farmers (Altieri, 2002; Vandermeer & Perfecto; 2013; De Abreau & Bellon, 2013).

The East African standard for *Organic Agriculture* (OA) states that 1) Organic agriculture is a holistic production management system, which promotes and enhances agroecosystem health, including bio-diversity, biological cycles and soil biological activity, 2) It seeks to minimise the use of external inputs, avoiding the use of synthetic drugs, fertilizers and pesticides and aims at optimising the health and productivity of interdependent communities of soil life, plants, animals and people and 3) It builds on East Africa's rich heritage of indigenous knowledge combined with modern science, technologies and practices (East African Community, 2007). The regulation of organic agriculture of the European Union states as objectives for OA to respect nature's systems and cycles and sustain and enhance the health of soil, water, plants and animals and the balance between them; to contribute to a high level of biological diversity and to make responsible use of energy and the natural resources, such as water, soil, organic matter and air [European Commission (EC), 2007]. The Canadian organic regulation defines OA in a similar way and also emphasizes the main role of maintaining and benefitting from above and below ground biodiversity (Canadian General Standards Board, 2006).

Thus, Agro-ecological and organic agriculture aims at protecting and benefitting from ecosystems services by renewing and maintaining critical natural capital as a basis for agricultural production. Ideas of Intensification of organic agriculture builds on principles of recycling of organic matter and nutrients at field, farm and landscape levels and benefitting from sustaining biodiversity. The term "*eco-functional intensification*", was introduced in a research strategy for the improvement of organic agriculture in Europe: Intensification of land use and agriculture by means of improved knowledge and application of biological principles and agro-ecological methods and increased cooperation and synergy between different components of agro-eco systems and food systems (Niggli et al., 2008). While this overlaps with objectives stated in the broader definitions of SI and in some approaches to "climate smart agriculture" (Lipper et al., 2014) the deliberate minimal use of external chemically based inputs in agroecology and organic farming ideally enhances the focus on eco-functional intensification strategies.

Several of the mentioned discourses and schools of thought regarding the future of agriculture have their merit under different natural and sociocultural conditions and most likely organic/agroecological based systems will co-exist with different (improved) conventional systems and they will co-develop over the next decades. In the following we will focus on the perspectives of organic and agroecological practices for improving current food security and for securing and maintaining food security in a long term perspective and the challenges these systems face.

## 3. Yields in OA and potential for Eco-Functional Intensification

A wide number of comparisons of organic vs conventional crop yields have been produced over the last four decades based on long terms trials and on recorded yields in private farms. De Ponti et al. (2012) analysed 362 paired sets of organic-conventional yield data covering 67 crops from 43 countries and reported that on average organic yields are 80 % of those obtained under conventional agriculture. They also stated that relative yield differ across the region of the world; lowest in Northern Europe (70%) and highest in Asia (89%), relative yields differed between crops with soybean, some other pulses, rice and corn scoring higher than 80% and wheat, barley and potato scoring lower than 80%. Te Pas and Rees (2014) found on average 26% higher yields in organic farming in a review of organic vs conventional comparison studies specifically from Tropics and sub-tropics and with the largest yield difference in least developed countries and dry growing conditions.

In the largest and most recent meta-analysis of organic vs conventional yield comparisons Ponisio et al. (2014) found that across 1071 observations from a total of 115 comparison studies the organic yields were 15.5-22.9%

lower than conventional (95% interval and average 19.2%). Contrary to earlier studies they did not find significant differences in the yield gap for certain crops such as leguminous crops but for the categories perennials and roots/tubers, the variation in yield difference was larger than for annual crops as a whole. Similarly, this study did not demonstrate significant effects of nitrogen or phosphorus levels on the yield comparison. However, the results did show that yields in more diversified organic cropping systems with either diverse crop rotations or multi-cropping were only 9% and 8% lower on average, respectively when compared to conventional monocultures. Whether this is a relevant comparison depends on whether one considers organic crop production to be more diversified at field and farm level as a systemic function. In any case it demonstrates a yield potential of diversification practices which is an inherent principle of agroecology and organic agriculture and thus is part of eco-functional intensification strategies.

Critics of organic agriculture find that yields are too low and that options for improving total yields without being indirectly or directly dependent on conventional farming are limited (Kirchmann et al., 2008; Connor, 2008). Kirchmann et al. (2008) states that organic manure would not be available in sufficient amounts to allow a significant upscaling of organic agriculture with yields comparable to conventional. Therefore, organic crop rotations need to include green manure and if these crops are not harvested for feed then the total crop yield calculated from organic rotations should be discounted for the years with no crop export from the fields. On the other hand, organic systems with ruminants which may utilize large proportions of grass-clover or other leguminous forage crops often have sufficient and continuous N inputs to the soils which again may supply other crops with Nitrogen if grown in a rotation (Halberg et al., 1995; Kirchman et al., 2008).

Kremen and Miles (2012) presents evidence of significant advantages of biologically diversified farming systems in terms of biological regulation of agricultural pests (insects, weeds and diseases including soil pathogens), pollination and soil quality maintenance and water holding capacity. This enhances resilience and reduces the negative impact of farming on important ecosystems services. However, the degree to which this also supports high and increasing yields is less clear and is context dependent. Kremen and Miles mostly use organic vs conventional comparisons to discuss the yield potential of biologically diversified farming but stress that this is an insufficient test since most organic systems set up in comparison trials do not include intercropping or other diversification strategies. Moreover, there is a lack of yield assessments which go beyond single crops and integrate the total edible output harvested from diversified agriculture systems.

The potential of agroecological practices for improving and sustaining yields is better documented in tropical agricultural systems than in high input systems in temperate regions (Perfecto et al., 2009; Altieri et al., 2012). Examples include the Push Pull system of intercropping maize for the control of stem borer and Striga, which has proven higher yields than conventional maize growing in large parts of East Africa (Khan et al., 2011). Agroforestry systems where trees supply nutrients for annual crops through leaves incorporated into soils (“fertiliser trees”) have proven to support yields of maize comparable to high fertilizer supply (Garrity et al., 2010; Akinnefesi et al., 2010). Akinnefesi et al. (2010) reports that when the fertiliser trees are used in combination with 50% additional kilograms of N and P fertiliser, Maize yields were higher than when using fertiliser alone. Moreover, fertiliser trees can reduce weed problems and improve soil properties such as water uptake and P-supply. A few examples of agroforestry and other types of intercropping in Europe demonstrates potential for improved total yield and resource use, which however is not widely used in practice (Malézieux et al., 2009).

Most of the options and practices described in the previous paragraphs would be in accordance with the principles of organic farming and agroecology. In conclusion, there is evidence of well-functioning organic and agroecological farming systems with yields comparable to conventional or with relatively small yield differences. On the other hand, in high input areas yield differences can be larger and strategies for EI needs to be significantly improved in light of the triple challenge (increased biomass demand, preservation of ecosystems services, climate change).

## 4. Short to Medium Term Perspective

The examples of improved local food security from introducing agro-ecological and low external input agriculture practices among smallholder farmers are many (FAO, 2013). In a widely cited study Pretty et al. (2006) collected and interpreted self-reported data from a large sample of 208 development projects in Africa and Asia. They documented success in increasing food production per hectare by 50-120 percent using a number of improvements and interventions which the authors classified in four strategies: A. Intensifying the “kitchengarden”, B. Introduction of new elements in the farming system (e.g. fishponds or multipurpose trees), C. Better exploitation of soil, water and organic material (e.g. mulching), D. yield increase in staple foods (e.g.

pulses, better seeds). Altieri et al. (2012) report similar successes in improving yields and food security by development and utilization of agroecological practices in Cuba, Brazil and the Philippines.

While most – but not all - of the interventions described in the survey by Pretty et al. (2006) fall within the definitions of agroecology and organic agriculture few were certified organic schemes. The effects of increasing poor farmers' production capacity using organic agriculture and agroecological practices partly depends on whether a project aims at supplying *certified organic products* to a high value market or aims at increasing production and quality by *informal use of organic principles* and agroecological practices. While the certified approach often links smallholder farmers to a high value market and thus improves their income and livelihood including food security this type of project does not necessarily create holistic improvements in the overall farming system if the focus of intensification is limited to a single cash crop (Panneerselvam et al., 2013b). Also, the total effect of higher prices on cash crops from small areas can be modest (Pannerselvam et al., 2012; Ayuya et al., 2015). Contrary, projects like the majority of the cases in Pretty et al. (2006) which focus on agroecological methods, may be closer aligned with organic principles and express a holistic approach to integration of local and scientific knowledge for farm level intensification and building of natural, human and social capital (also called informal organic systems, Pannerselvam et al., 2013b).

In three linked case studies in India Panneerselvam et al. (2011) studied the impact of conversion to organic agriculture on the food security of small holding farmers in relation to market orientation and local conditions. The study found examples of both certified and informal organic agriculture with similar differences in the main effects. One case study in Madhya Pradesh (Central part of India) farmers were linked with a company focusing on introducing organic cotton production for export and farmers were trained by training institute, BioRe Association, in agroecological methods such as composting of local manure and growing pigeon peas as intercrops. Main results were that the families improved their food security mainly by the combined effects of reduced debts (due to the reduced need for borrowing cash at high interest rates for fertilizer and pesticides against the harvest sales) and increased self-sufficiency of protein food from the intercrops. Moreover, the price premium on organic cotton compensated for the lower yields. In two case studies the market orientation was less prominent due to NGOs promoting informal organic farming for improving the households' food security. In Tamil Nadu the local NGO Center for Indian Knowledge System (CIKS) provides training programs for organic farmers on soil conservation, vermicompost production, and managing pest and disease organically. CIKS facilitated farmers association for marketing the non-certified organic products with 10 percent price premium. The surveyed conventional farms in Tamil Nadu were high-input systems and the organic were in a conversion period, hence low yield was the biggest challenge for organic farmers. Nevertheless the study found that organic farmers improved their food and nutritional security by increasing net income (by 34% reduction in input costs) and increasing pulses production by 26% even though total farm production decreased by 5% (no price premium was incorporated in this estimation).

There is a need for more thorough and systematic investigations into the potential for EI or eco-functional intensification based on agroecological principles and practices in light of future increasing crop production and food needs (Malézieux et al., 2009; Doré et al., 2011; Caron et al., 2014; Maraux et al., 2013). The linkage between the following two approaches could be improved: One, a coordinated effort recording developments in crop and livestock production and food security across a wide set of development projects (NGO's, Governments, market driven) using mutually agreed standard recording and assessment methods at field, farm and landscape levels of scale (see also Shennan, 2008). Second, a set of coordinated research sites for testing of agroecological practices complemented with in-depth research into biological and bio-physical processes to support the interpretation of results in terms of yield trends, variation and resilience and the development in other ecosystems services related to changes in natural and human capital in the research site.

In conclusion, there is abundant evidence that food security may be improved in resource poor rural environments by agroecological and organic approaches where principles of eco-functional intensification are applied in participatory processes of co-development and learning to jointly build human, social and natural capital (Halberg & Muller, 2013). Two main questions remain, however. First, how to outscale these knowledge intensive methods and practices (which at the least requires significantly higher investments in agricultural research and development for EI) and second, whether eco-functional approaches to intensification will be sufficient for the further EI/SI in order to meet the growing food demands towards 2050? This is the focus of the next section.

## 5. Upscaling and the Long Term Perspective

Some examples exist of scenarios testing consequences for food security of upscaling of OA or agro-ecological farming to larger areas with or without considering population growth and/or diet changes.

Bagdley et al. (2007) modelled the effects of upscaling organic agriculture to global level based on a review of conventional to organic yield differences and assumptions regarding availability of organic manure in combination with legumes for Nitrogen fixation. They estimated that the global food production after conversion would be sufficient to cover current needs for calories and protein with 2600-2700 kcal per capita per day. And given optimistic assumption of doubling yields in developing countries after conversion to organic they estimated a food availability of 4800 kcal per capita and day. However, the assumptions made by Bagley et al. (2007) were disputed especially as concerns the high relative organic yields in developing countries (Kirchmann et al., 2008; Kremen & Miles, 2012) and the assumptions regarding availability and redistribution of Nitrogen from Biological Nitrogen Fixation (Connor, 2008).

The findings from three case studies in India cited above were used as a basis for testing food security consequences in scenarios for upscaling organic agriculture to large areas in Tamil Nadu. On a regional basis Panneerselvam et al. (2013a) assessed the economic situation of marginal and small farm types under a large-scale organic scenario and the consequences for regional food production in two states of India -Tamil Nadu and Madhya Pradesh. Marginal and small farms cultivates 3.4 million ha (60% of area of all farm types) in Tamil Nadu and 4.8 million ha (27% of area of all farm types) in Madhya Pradesh. Conversion of these farms into organic based on current relative organic yields would lead to lower food production at state level, 5% in Tamil Nadu (Figure 1a) and 3% in Madhya Pradesh (not shown) over baseline. However, conversion of rainfed areas exclusively was beneficial by producing 13 and 4% more food in Tamil Nadu (Figure 1a) and Madhya Pradesh (not shown), respectively, compared to their rainfed baseline, whereas conversion of irrigated areas exclusively had a negative impact on regional food production. Large-scale conversion of marginal and small farm types improved their income due to reduction in costs of production and price premium for organic products (Figure 1b). The Gross margin calculated as crop value (harvest yields times market prices) minus variable costs A was 26% higher in the organic scenario and was partly dependant on the organic price premium. However, the conventional farmers (baseline) have specific government support in terms of fertiliser subsidies, currently not available to organic farmers.

Modelling a situation where such subsidies were equalised between different types of fertiliser (chemical vs organic/green manure) demonstrated the potential for improving further the Gross Margin of organic farmers, which could be twice as high as in the baseline . Organic farms would have higher net income in the hypothetical situation of no fertilizer subsidy (Figure 1B, Gross Margin B), and this did not include the likely outcome of improved organic yields over current scenarios if fertiliser subsidies were diverted also to cover green manures. The large-scale organic scenario has potential to improve the food security by increasing the income and reducing the debt (80% of the food insecure people in India suffer mainly from low purchasing power), and would play a major role in improving their nutritional security (50% of Indians suffer from protein malnutrition) by producing more protein rich pulses by intercropping, mostly consumed locally. India has been a net exporter of cereals and a net importer of pulses, the traditional protein source. The scenario changed rural food production to a higher degree of protein self-sufficiency, but without improvement in organic yields this could induce a (limited) reduction in food calories, unless the organic yields were improved for example by diverting subsidies or include green manures.

The upscaling by Badgley et al. (2007) and Pannerselvam et al. (2013a) used current yields and yield differences and known crop cultivation technologies to assess food production and security. However, in forecasting the consequences of different agricultural development pathways towards the predicted growth in food needs it would be necessary to include other assumptions regarding technological improvement, knowledge uptake and thus possible yield gains through e.g. eco-functional intensification. However, in a long term perspective it is pertinent to consider how different forms of EI or SI may reverse this trend, improve agriculture's relation with other ecosystems services and at the same time be resilient to climate change.

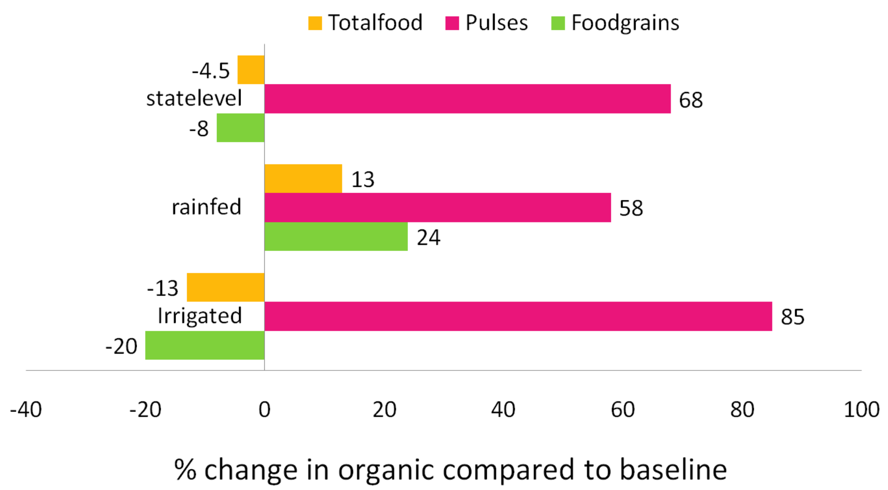


Figure 1a. Food production % change in Tamil Nadu

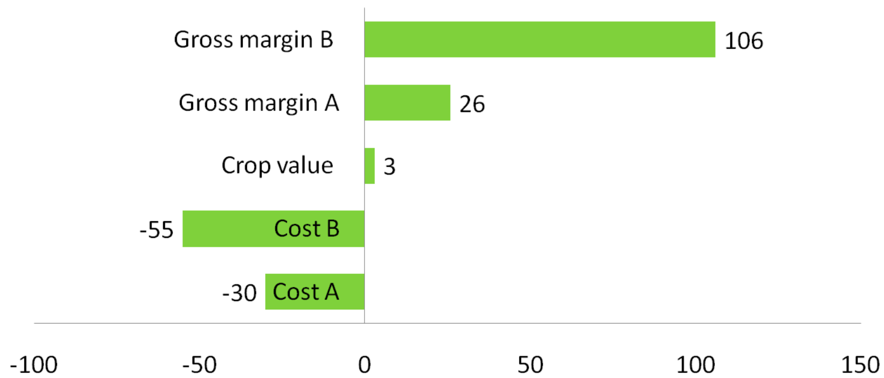


Figure 1b. Economic comparison % change in OA compared to baseline (Tamil Nadu)

Cost A = variable cost.

Cost B = Cost A+ cost of fertilizer subsidy (simulating "flexible subsidy").

Crop value = yield*market price+10 % premium for organic products.

Grossmargin A = Crop value – Cost A.

Grossmargin B = Crop value – Cost B.

A few macro level and global level scenarios have compared conventional intensification with eco-functional intensification and agro-ecological pathways. In the so called "Agrimonde study" Paillard et al. (2011) compared a business as usual scenario, relying on conventional agriculture, with an alternative scenario, relying on agroecological intensification (AEI). The Agrimonde AEI scenario shows that global food needs can be met even with low productivity increase assumptions, but partly because this alternative scenario also goes with more fundamental changes in animal production systems and in food consumption patterns. Thus, assumptions of reduced livestock based food in wealthier consumers' diets are intrinsic to this modelling. Therefore, the capacity of agroecological systems to produce enough food globally in 2050 still remains questionable in this scenario, due to the difficulty to change food consumption patterns over the same period, but such a scenario does not seem more questionable or less credible than the business as usual scenario. Common assumptions of the business as usual scenario can be considered as too optimistic, particularly with a very high level of increases of yields in regions where yields are already very high or even saturating, like in South and East Asia. This is also the case for North Africa and Sub-Sahara Africa, where the assumed yield increases seem very high compared to the potential very high impacts of climate change in these regions (Lipper et al., 2014; Porter et al., 2014). The business as usual scenario developed by Agrimonde with reference to the most common assumptions present in other scenarios from the literature therefore shows that conventional agriculture scenarios generally rely on very optimistic assumptions of technological progress in increasing yields, which seems very questionable in a context of degraded soils and increasing climate change.

On the other hand, the AEI scenario relied on very prudent, minimal assumptions of yield increases, taking into account potential extreme events due to climate change. In particular, based on more recent studies discussed here above, the productivity assumptions for agroecological systems in Africa could be made much higher in the agroecological scenario, showing a much better capacity of sub-Saharan Africa to feed itself, measured in terms of food availability for the continent. The improved access, stability or diversity in uses provided by agroecological systems then also adds to the conclusion of the Agrimonde study that agroecological innovation pathways can be a very good candidate for ensuring global food security in 2050.

The results of the Agrimonde scenarios converge with the study by Erb et al. (2009), where a variety of combinations of changes in food diets and in agricultural production systems was computed to test their capacity to rely on the cropping potential of the planet to feed humanity without damaging land to be preserved for biodiversity. This study develops scenarios where a convergence of diets towards the current western diet are not compatible with a conversion to an agroecological/organic pathway for agricultural systems, but a solution space does exist for an organic transition pathway if a lower consumption of animal products is assumed, and with an increase of cropped area of around 20% over the next 40 years. Such a scenario is questionable with regard to its consequences on biodiversity, through the expansion of cropped area it entails, but the FAO business as usual scenario also relies on increases in cropped area.

All these scenario exercises cannot represent, for the moment, the changes in supply chains, markets, linked to the diversification of crops in an agroecological scenario. They are therefore still weak in their capacity to discuss the feasibility and the performance of such a future development. The combination of different crops in the same rotation, on the same plot, or of different productions in the same production system is one of the key characteristics that make agroecological systems more resilient to climate or market shocks, more interesting in terms of nutrition, and also more productive than if measured only through the lens of the productivity of only one of the crops as discussed above. Including such a perspective in global modelling exercises is thus one of the key challenges for future research.

Kirchmann et al. (2008) considers current organic yield differences to conventional in the long term perspective and finds it unlikely that organic agriculture may feed the growing populations towards 2050 without drastic increases in cropped land, which they find unrealistic and problematic due to habitat loss and other environmental consequences. They do not, however, discuss options for increasing yield trends in organic agriculture or other means of limiting crop needs, such as diet changes or reduced waste. In this light, an important question is to what extent yields in organic agriculture may improve over the next decades, for example due to more research and innovation and better application of knowledge and good practices by farmers.

Halberg et al. (2006) used the “Impact” model to estimate the consequences of large scale conversion to OA in high input (Intensive) regions (Europe, North America (ENA)) and in low input regions (Sub-Saharan Africa (SSA)) under different assumptions of relative yield trends in organic and conventional crops towards 2020 compared with a baseline. Organic yields across 19 different crop commodities were estimated to be 60-100% of conventional yields in high input regions and 80-120% in low input regions. They tested different assumptions in separate model runs converting 50% of agriculture to organic in either high input regions or low input regions. An important assumption was the yearly yield growth rates from technological improvements in organic relative to baseline (conventional) yield gains over the 25 year modelling time span. Relative yield growth rates tested were 125, 150 and 200% higher yield growth rates in organic, Table 1. One assumption for this was that due to a previous lack of investment in research and development aimed at organic agriculture it would be possible to improve yields more in the future compared to conventional agriculture given the sufficient allocation of funding and resources. The Impact model uses this type of input to estimate yearly land allocation per crop/commodity type by region forming a global coverage and comparing this to regional and global food needs estimated from population numbers and economic indicators, for example purchasing power. The model was calibrated to the year 1995 and simulations of baseline scenario and organic scenarios were performed as a series of yearly simulations integrating assumptions, such as population growth, economic development and technological development by region. In each of five different scenario model runs only ENA or SSA was converted to 50% organic agriculture and for all scenarios the outcome was presented in the form of World prices for selected food crops, the economic food demand (not to be confused with food needs) in SSA and the resulting food security in

SSA, Table 1. Surplus and deficit of commodities were assumed to be traded between regions using purchasing power as an important driver, thus reflecting that food is traded globally. Therefore, reduced yields in ENA might increase global crop prices on the world market and potentially impact negatively on food security in poor regions (e.g. SSA) if there is not sufficient locally produced food. The results demonstrated that a large scale conversion of 50% of the land into organic agriculture in ENA would not impact the food security in SSA significantly (Table 1). However, the model also projected that economic demand for cereals and soybean, which are the main commodities traded globally, could be reduced in SSA as a consequence of higher world market prices. The reduced demand for cereals and soybean in SSA might result in small reductions in food availability (1-2% less kcal per capita) and subsequent increases in malnourished children (used as a proxy indicator for food security in the model). Increases in relative yield growth rate in organic crops in ENA resulted in lower impacts on world prices and food security in SSA (Table 1). The percent malnourished children are predicted to be slightly negatively influenced by higher world prices under these scenarios unless the organic yields grow more than conventional or food needs in SSA are better covered by increased local production and consumption of crops not included in the modelled commodities.

The two scenarios for conversion of 50% of SSA land to organic agriculture demonstrated a potential benefit if the yield growth rate was similar or slightly higher than the baseline (Table 1, right side). The baseline scenario projected an increase in imports of cereals to SSA because the expected conventional yield increases would not be sufficient for domestic food to compensate for population growth over the 25 years. This reduced self-reliance of food in SSA is a serious threat to food security because world market prices might become more volatile. This could be reversed in the organic scenarios for SSA, pointing to a higher degree of food security based on local food access. The assumptions of higher organic yields resulted in a lower projected import of cereals compared to baseline scenario, especially for the category "Other coarse grains" (millet, sorghum the local staple food in poorer regions) whereas the assumed lower organic yields in soy beans would lead to increased import needs (Table 1).

The Impact model was not entirely suitable for more in-depth studies of the consequences of organic agriculture or EI for food security because the commodities are treated separately and not as part of integrated farming systems and because synergies from, for example crop diversification and other agroecological practices, could only be simulated with rather coarse assumptions built into the factor for “relative yield growth rates”. On the other hand, the simulation exercise demonstrated the challenge of increasing the yields over time in organic agriculture for this to be a relevant strategy for EI and improving global food security in light of growth in populations and in economic prosperity. This is even more so, since the modelling did not account for the more recent knowledge of the possible impact of climate change and erosion of soil and ecosystems services on local food production in SSA or the impact of the growing allocation of crops for non-food purposes on global food prices.

As mentioned there are several discourses of agricultural development and linked with this also different opinions of the way to address changes in food demands. There is a difference between seeing the question of people’s diet choices as either extrinsic or intrinsic characteristics of food systems. Or put in simplistic terms: Should development ideas of future agriculture take the predicted increases in food consumption (especially of livestock products) for granted or should ideas of improved and changed diets and/or reduced waste be integrated in the agricultural development scenarios? Garnett et al. (2013) stress that the aim for sustainable intensification should not narrow dietary options, especially for poor consumers, by e.g. standardizing food choices to few high yielding commodities, which might risk aggravating micronutrient and protein deficiencies. Thus, SI farming strategies need to take nutrition into account and should also build on improved understanding of the role of wild food and indigenous crops in diets.

Table 1. Relative production after 50% conversion to organic farming in Europe and North America (ENA) and in Sub Saharan Africa (SSA) respectively for five separate model runs. Resulting world prices, and food demand in SSA modelled over a 25 year period. Results presented as percent of projected results of IFPRI's baseline scenario for 1995 (After Halberg et al., 2006)

| **Conversion Scenario** | **ENA** | **ENA** | **ENA** | **SSA** | **SSA** |
|---|---|---|---|---|---|
| Relative Yield Growth Rate (% of baseline) | 100 | 150 | 200 | 100 | 125 |
| **Production in region where conversion is modelled** | | | | | |
| Wheat | 92 | 95 | 97 | 89 | 92 |
| Maize | 90 | 92 | 94 | 105 | 108 |
| Other Coarse Grain | 92 | 95 | 97 | 106 | 109 |
| Sweet Potato and yam | | | | 104 | 107 |
| Cassava | | | | 105 | 105 |
| Soybean | 87 | 89 | 92 | 95 | 98 |
| **World Prices** | | | | | |
| Wheat | 111 | 107 | 103 | 100 | 100 |
| Maize | 112 | 109 | 106 | 99 | 98 |
| Other Coarse Grain | 113 | 109 | 105 | 98 | 96 |
| Sweet Potato & Yam | 114 | 110 | 106 | 96 | 94 |
| Cassava | 109 | 106 | 103 | 92 | 89 |
| Soybean | 108 | 106 | 104 | 100 | 100 |
| **Food Demand in SSA** | | | | | |
| Wheat | 94 | 96 | 98 | 100 | 100 |
| Maize | 97 | 97 | 98 | 100 | 100 |
| Other Coarse Grain | 96 | 97 | 98 | 101 | 101 |
| Sweet Potato & Yam | 100 | 100 | 100 | 100 | 100 |
| Cassava | 101 | 101 | 100 | 100 | 100 |
| Soybean | 95 | 95 | 96 | 100 | 100 |
| **Food Security in SSA** | | | | | |
| Food Availability (Kcal/capita) | 98 | 99 | 99 | 100 | 100 |
| Total Malnourished Children | 101 | 101 | 101 | 100 | 100 |
| Net imports to SSA | | | | | |
| Wheat | | | | 100 | 100 |
| Maize | | | | 98 | 97 |
| Other Coarse Grain | | | | 90 | 84 |
| Soybean | | | | 104 | 102 |

## 6. Conclusions

Eco-functional intensification for improved local food security has been documented in practice in poor rural regions and increasingly research is backing the development of agroecological methods for smallholder farmers in developing countries mainly in tropical areas. However, little documentation exists of the actual potential for upscaling to cover urban food demand now and in future. Foresight scenarios suggest that yields will have to be raised significantly in organic and similar agroecologically based farming systems for these to play an important role in satisfying the increasing crop needs towards 2050. The consequences of upscaling organic and agroecologically based farming based on eco-functional intensification in high intensive areas without changes in diets towards less animal products per capital are unclear. There is still a need for better foresights and scenarios for global and regional food security based on eco-functional intensification and development. Diet choice must necessarily be considered an endogenous factor in global food security scenarios. Moreover, for such scenarios to be useful more evidence based knowledge on the potential yield increments from eco-functional or Ecological intensification strategies is required.

The paradigms and research areas of agroecology, ecological and eco-functional intensification are promising in terms of building synergies between agriculture and other ecosystems services for improved yields, natural capital and resilience. Organic agriculture and the agroecology movement are the most prominent examples of ecological intensification strategies that have developed into sustainable systems based on low or no chemical inputs with lower but comparable yields to conventional agriculture. An increased effort of research and innovation in these systems using combinations of agronomy, biology and molecular sciences will most probably allow for improving yields of organic and agroecological farming while maintaining or improving sustainability and resilience. Part of this should be attempt at further "systems re-design" where agriculture would be adapted to a wider landscape approach using insights from biodiversity and agroforestry and coordinated land use for purposes of food and other biomass.

There is a need for more thorough and systematic investigations into the potential for eco-functional intensification based on agroecological principles and practices in light of future increasing crop production and food needs linking systematic recordings of improvements in different development projects and a network of coordinated research sites. Continuous results coming from such linked efforts would give more precise interpretations of the necessary improvements in production and potential improvements based on ecofunctional intensification and agroecology and synergies with other ecosystems services including consequences for sustainability and resilience.

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