UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

WORKING PAPERS IN ECONOMICS

No 526

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April 2012

ISSN 1403-2473 (print)
ISSN 1403-2465 (online)

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Reducing Global Warming and Adapting to Climate Change: The Potential of Organic Agriculture

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ABSTRACT**:** Climate change mitigation is urgent, and adaptation to climate change is crucial, particularly in agriculture, where food security is at stake. Agriculture, currently responsible for 20-30% of global greenhouse gas emissions (counting direct and indirect agricultural emissions), can however contribute to both climate change mitigation and adaptation. The main mitigation potential lies in the capacity of agricultural soils to sequester CO_2 through building organic matter. This potential can be realized by employing sustainable agricultural practices, such as those commonly found within organic farming systems. Examples of these practices are the use of organic fertilizers and crop rotations including legume leys and cover crops. Mitigation is also achieved in organic agriculture through the avoidance of open biomass burning, and the avoidance of synthetic fertilizers, the production of which causes emissions from fossil fuel use.

Common organic practices also contribute to adaptation. Building soil organic matter increases water retention capacity, and creates more stabile, fertile soils, thus reducing vulnerability to drought, extreme precipitation events, floods and water logging. Adaptation is further supported by increased agro-ecosystem diversity of organic farms, based on management decisions, reduced nitrogen inputs and the absence of chemical pesticides. The high diversity together with the lower input costs of organic agriculture is key to reducing production risks associated with extreme weather events.

All these advantageous practices are not exclusive to organic agriculture. However, they are core parts of the organic production system, in contrast to most non-organic agriculture, where they play a minor role only.

Mitigation in agriculture is however not restricted to the agricultural sector alone. Consumer preferences for products from conventional or organic farms, seasonal and local production, pest and disease resistant varieties, etc. strongly influence agricultural production systems, and thus the overall mitigation potential of agriculture. Even more influential are meat consumption and food wastage. Any discussion on mitigation of climate change in agriculture thus needs to address the entire food chain, and to be linked to general sustainable development strategies.

The main challenges to dealing appropriately with the climate change mitigation and adaptation potential of organic agriculture, and agriculture in general, stem from a) insufficient understanding of some of the basic processes, such as the interaction of N_2O emissions and soil carbon sequestration, contributions of roots to soil carbon sequestration, and the life-cycle emissions of organic fertilizers, such as compost; b) lack of procedures for emissions accounting which adequately represent agricultural production systems with multiple and diverse outputs, which also encompass ecosystem services; c) the problem to identify and design adequate policy frameworks for supporting mitigation and adaptation in agriculture, i.e. such that do not put systemic approaches at a disadvantage due to difficulties in the quantification of emissions, and in their allocation to single products; d) the necessity to assure that the current focus on mitigation does not lead to neglect of other factors influencing the sustainability of agriculture, such as pesticide loads, eutrophication, acidification or soil erosion; and e) the open questions, how to address consumer behaviour and how to further changes in consumption patterns, in order to utilize their mitigation potential.

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The goal of this text is to provide a timely, short, understandable but nonetheless comprehensive and critical overview of the links between organic agriculture and climate change. It outlines the mitigation and adaptation potential of organic agriculture and addresses main opportunities, challenges, institutional and policy aspects, thus placing this discussion in a broader context, which also addresses consumer aspects and policies. For further details see the references given in the text and Kotschi and Müller-Sämann, 2004; Niggli et al., 2007, 2009; El-Hage Scialabba and Müller-Lindenlauf, 2010; Muller et al., 2011; Muller and Aubert, forthcoming; Muller et al., forthcoming.

MITIGATION

1. Maintaining and increasing **soil organic carbon** in agricultural systems is the option with the largest mitigation option in agriculture (Smith *et al.*, 2008). Organic agriculture (OA) has a significant potential contribution in this respect: practices that are commonly used on organic farms (use of organic fertilizers, fertility building leys with legumes and cover crops) further the production of soil organic matter (Smith *et al.*, 2008; Leifeld and Fuhrer, 2010, Chirinda et al. 2010a).

2. Organic agriculture has lower **N_2O emissions** from nitrogen application, due to lower overall nitrogen input per ha than in conventional agriculture (Mäder *et al.*, 2002, Olesen et al. 2006). In those cases, where the yields are lower on organic farms, comparisons made per kg of product are less favourable for organic systems (Chirinda et al., 2010b) unless N use efficiency is higher on organic farms (cf. 4 below). The type of N input and how it is managed most likely plays a considerable role for N_2O emissions, but much still needs to be understood regarding the role of N inputs in organic form.

3. **Open burning** of crop residues and biomass waste is prohibited for agriculture in most industrialized countries, but it is still common practice in conventional agriculture in many developing countries. In organic agriculture, biomass is not burned, but recycled to the soil to improve fertility. This reduces the CH_4 and N_2O emissions in comparison to conventional agriculture, where crop residues are often burnt on the field (Smith *et al.*, 2007)

4. Conventional stockless arable farms depend on the input of synthetic nitrogen fertilizers, while stockpiled manure and slurry on livestock farms create additional emissions and other environmental problems. Organic farms mitigate such problems by on-farm or cooperative use of farmyard manure between crop and livestock operations (El-Hage Scialabba and Müller-Lindenlauf 2010). In particular where this leads to an overall increase in N use efficiency, the result is a reduction in emissions per kg of product (Olesen et al., 2006).

5. Due to reduced concentrate feed use in **ruminant animal husbandry**, organic animal agriculture causes less direct land use change (deforestation to gain cropland for concentrate feed production) and thus also less CO_2 emission from soil carbon losses due to this change. Since organic grassland and fodder production is often equally productive as with conventional systems there are little indirect land use change effects. On the other hand, higher roughage diets can lead to higher methane emissions from ruminants (Shibata and Terada, 2010). The net effect of increased roughage nonetheless yields an overall reduction in emissions. Research comparing ruminant livestock production systems also shows that organic farming systems perform favourably, in terms of energy use, due to energy savings associated with reliance on clover-grass leys and high forage/low cereal diets (Lampkin, 2007). In addition, animal welfare is improved, as a high roughage diet is more natural for ruminants (Zollitsch *et al.*, 2004). Furthermore increased longevity within organic systems reduces the relative emissions from the unproductive rearing phase of dairy cows (Lynch *et al.*, 2011).

6. Ca. 1% of global fossil energy consumption is used for **chemical nitrogen fertilizer** production. Organic agriculture does not contribute to these emissions, as no chemical nitrogen fertilizers are used. In organic agriculture, nitrogen input stems from the use of nitrogen fixing leguminous plants and the application of manure and compost. Biological N fixation is not in itself a source of N_2O (Rochette and Janzen, 2005), but soil incorporation of N-rich plant residues from legume crops can lead to high emissions of N_2O (Moller and Stinner, 2009). More research is however needed to determine the relative performance of organic vs. chemical fertilizers, based on lifecycle emissions and including interactions with soil carbon levels. To give justice to the systemic aspects of organic agriculture, one needs to go beyond the mere comparison of fertilizer types. The fact that organic systems are based on lower nitrogen inputs, closed nutrient cycles and combined animal and plant production needs to be accounted for, and this requires a holistic perspective on the accounting of greenhouse gas emissions from farming systems. Furthermore, there are strong indications from many cases that application of synthetic nitrogen fertilizers can lead to losses of soil organic matter (Khan et al. 2007, Mulvaney et al. 2009). Generalisation

of these findings is however discussed controversially (Ladha et al. 2011; see also the various comments and replies on the two articles mentioned above).

7. In the majority of cases, organic farming systems use less **fossil energy** on a per hectare and per unit of food produced basis, than conventional farming systems (Schader et al. 2011). Energy use in OA is 20-30% (crop farms, per ha: based on corn and soybeans) to 50% (livestock, per kcal meat protein: organic grass-fed beef vs. conventional grain-fed beef) lower than in conventional agriculture (Pimentel *et al.*, 2005; Pimentel, 2006). The lower energy use on organic farms is largely because industrial fertilizers and pesticides are not used, thus avoiding the energy inputs for their production. (Lampkin, 2007). However, in cases where the yields of organic farms are lower, the energy input per unit output can also be higher (Cormack and Metcalfe, 2000). This is the case for potatoes, for example. Weed control can also pose particular challenges to organic systems, thus potentially increasing tillage needs and corresponding energy consumption. But on the average, the increased machinery use requires less energy, than needed for fertilizer production (Cormack and Metcalfe, 2000). An exception is flame weeding of organic carrots.

8. **Further mitigation options** in agriculture include a) on-farm biogas production from agricultural waste, in particular from manures and crop residues; b) optimized manure and slurry management (optimized stables) and storage (coverage); c) use of resistant varieties and effective crop breeding (to reduce energy needs for spraying and to increase productivity); d) reduced tillage to increase soil carbon contents; e) increased efficiency of machinery and their use (e.g. optimal tire pressure and speed on the fields) and of buildings to reduce energy use; f) non-permanently flooded rice production; this avoids methane emissions, but may increase N_2O emissions, in particular at high N rates.

ADAPTATION

9. Farm practices commonly used within organic agriculture increase and stabilize **soil organic matter**. As a result, soils under organic management can better capture and store water than soils of conventional cultivation (Reganold *et al.*, 1987). Organic production is thus less prone than conventional cultivation to extreme weather conditions, such as drought, flooding, and water-logging (El-Hage Scialabba and Müller-Lindenlauf 2010), which are expected to become much more frequent under climate change (Ahmed et al. 2009). Organic farming practices have also been shown to reduce soil erosion (Siegrist et al. 1998), increase aggregate stability and stimulate soil biological activity (Lampkin, 2007). Organic agriculture thus provides protective responses to key consequences of climate change, particularly those associated with increased occurrence of extreme weather events, storms, droughts and floods. As already mentioned, these benefits do not depend on the implementation of OA as a whole system, but on implementation of certain key practices such as recycling of manures and crop residues through organic fertilizers, which can also be implemented in conventional agriculture.

10. Organic agriculture also increases **soil quality and fertility**, with regard to soil nutrients, improved soil structure and aeration, water retention capacity and thus water availability. The biological diversity of soil microbes, insects and earthworms is increased, all of which have important roles for soil quality (Mäder *et al.*, 2006).

11. Organic agriculture uses a greater level of diversity among crops, crop rotations and production practices than commonly employed in conventional, industrialized agriculture, which often is based on monocultures. Organic farms have a generally higher **biodiversity**, also due to set-aside areas and other landscape elements. This improves ecological and economic stability. The diversity of income sources, as well as the resilience to adverse effects of climate change is thus increased. An example of the benefits is the enhanced biodiversity, which reduces pest outbreaks and severity of plant and animal diseases, while also improving utilization of soil nutrients and water (Smith *et al.*, 2011). For improving resilience to a higher occurrence of heat waves under climate change, the use of agroforestry and shade trees can be a very efficient mechanism for lowering critical temperatures. These diverse systems may also enhance carbon sequestration (Smith and Olesen, 2010).

12. Organic agriculture is a **low-risk farming strategy** based on lowering external inputs and optimizing biological functions. Besides lowering toxicity, reduced inputs lower costs and thus contribute to the competitiveness of organic agriculture economically. In addition, organic price premiums may be realized. These factors working together can lower the financial risks and improve the rewards. They provide a type of low cost but effective insurance against crop reduction or failure (El-Hage Scialabba and Hattam, 2002; Eyhorn, 2007). Due to this increased coping capacity of the farms, the risk of indebtedness in general is lowered. Organic agriculture is thus most often a viable alternative for poor farmers. Risk management, risk-reduction strategies, and economic diversification

to build resilience are also prominent aspects of adaptation to climate change.

13. Organic agriculture provides a good opportunity to utilize **local and indigenous farmer knowledge**, adaptive learning and crop development, which are seen as important sources for adaptation to climate change and variability in farming communities. However, it is important to stress that existing local knowledge, in the front of climate change, needs to be updated by more intensive observations and their interpretation, as well as with the assistance of research, experimentation and innovation.

14. **Further adaptation options** include plant breeding for improved drought and heat resistance, use of locally adapted varieties (e.g. some traditionally grown local varieties) and optimized feeding practices to avoid heat stress for animals (e.g. early morning or night pastures).

OPPORTUNITIES

15. Organic agriculture can build on **well-established practice** with decades of use in various climate zones, and under a wide range of specific local conditions. There are other forms of sustainable agriculture, but due to the well-defined standardization of organic agriculture, and its strong acceptance, it provides a useful tool for policy makers.

16. Necessary **practice and knowledge for organic agriculture are thus readily available** for most aspects (an exception is reduced tillage). Organic agriculture in developing countries does not depend heavily on technology transfer and large-scale investments. This is of particular importance in the context of empowerment of the most vulnerable rural populations that largely live from agriculture.

17. **Financial requirements** of organic agriculture, as an adaptation or mitigation strategy are low. Additional costs come from extension services, providing information, and, if certified, certification costs.

18. A further benefit of organic agriculture is its role for **water protection and replenishment**. Absence of pesticides and chemical fertilizers reduces water pollution in general, and the reduced nitrogen input lowers contributions to eutrophication of water bodies and to N contamination, mainly as nitrate, of drinking water. Some research points out that timing and management of N inputs can be more important for this than the total amount of N applied (Askegaard et al. 2011). Reduced irrigation needs, due to protection against water evaporation (vegetative soil cover, mulching) and the better water harvesting capacities of soils also increase water availability. Of particular relevance in arid areas, is the capacity of healthy soils to capture dew. Under arid conditions, the annual amount of dew can be more than from precipitation.)

CHALLENGES

19. Critical points are **training, extension services and information provision**, as well as institutional structures, such as market access. These need to be available. It can also be risky if economic viability of a project depends on a certain level of organic price premium, as this increases the vulnerability to demand and price dynamics.

20. Of particular relevance are **yields and food security**. Doubts have been frequently expressed about the capacity of organic agriculture to produce as much food as conventional agriculture. Recent research has however shown that organic and other approaches of sustainable agriculture, particularly in developing countries and arid regions, can have considerably higher yields than currently used agriculture (Badgley *et al.*, 2007). Pretty et al. (2006) analyzed 286 projects in 57 countries, covering 37 million hectares and found that sustainable agricultural practices led to an average increase in yields of 79%. Focusing on their data from Africa, based on 114 projects in 24 countries, covering 2 million ha (UNEP-UNCTAD 2008), shows an average yield increase of 116%. Organic agriculture is thus acknowledged as being able to contribute to food security (Food and Agriculture Organisation of the United Nations FAO, 2007). A particular benefit of organic agriculture is that it usually performs better than conventional agriculture under water scarcity. In intensively farmed regions under optimal conditions, yields tend to be lower in organic than in conventional agriculture (Badgley *et al.*, 2007). In such contexts, organic agriculture has thus an increased land demand to provide the same amount of output. This discussion also relates to logistics and consumer aspects. In the context of such assessments, the current level-of-output may not be an adequate benchmark, as much fertile land is used to grow feeds for livestock production, primarily for meat production, which has large associated losses related to energy and nutrition for humans, and it also contributes greatly to emissions of greenhouse gases (Herrero et al., 2011). In addition, a huge amount of the final food produce is wasted or lost during storage (30-40% globally, Godfray *et al.*, 2010). Reducing wastage, as well as overconsumption, would also lower pressure to increase productivity.

21. **More research is needed**, in particular to increase knowledge on a) the sequestration potential

of above- and below-ground carbon input and how different crops, soil types, management practices and climate conditions affect this; b) the life cycle emissions of organic fertilizers; c) how to minimize emissions from mulching green manures and cover crops; d) the interaction of N_2O emissions and soil carbon contents; e) the adaptability of plants to environmental stress and optimal breeding strategies, f) the use of complex agro-ecological systems (including agro-forestry) to increase resilience to climate change and also enhance carbon sequestration, and g) the relevance and effect of differences in farming systems, i.e. not only in single practices on climate change mitigation and adaptation.

22. **Consumer aspects** are key. A high mitigation potential lies in increased preferences for organic products, reduced meat consumption and reduced food wastage (Godfray *et al.*, 2010; MacMillon and Middleton, 2010). The question of how to improve on these aspects poses major challenges. Public debates and information provision should be initiated as a starting point.

INSTITUTIONAL AND POLICY ASPECTS

23. Institutions need to have a systemic view and understanding of the issues. This would prevent complex agricultural production systems, such as organic agriculture, from being disadvantaged (e.g. by overly focusing on specific technologies). Mitigation and adaptation in agriculture have to deal with many **uncertainties** and - partly fundamental - **knowledge gaps**. This has to be taken into account when designing policy instruments and other institutions (e.g. on measurement, reporting and verification) for mitigation and adaptation in agriculture.

24. Due to the **systemic approach of OA and its multiple outputs**, comprising ecosystem services besides commodities, comparison of organic to conventional agriculture is difficult. Due account has to be given to the functional unit (e.g. GHG emissions per ha or per kg output) on which comparisons are based. Basing comparisons of farming systems on methods that are adequate for standardized, well-separable processes, such as often dominating in industry, may lead to negatively biased assessment of systemic approaches such as OA.

25. This problem is most prevalent in **life-cycle analysis**, where emissions per unit output are the most common metric. The current variation in data sourcing and allocation methods means there is a large influence of the analysts on the data and methods chosen (TRADA, 2009), which may be random or, regrettably, biased. This variation is particularly acute with regard to N_2O emissions from fertilizer production and use, and rates of soil carbon sequestration under different management practices.

26. Uncertainties and institutional challenges are of particular importance when assessing **concrete policy instruments** for climate change mitigation. In particular offset mechanisms, such as the Clean Development Mechanism or Emissions Trade, where emissions in one location can be offset by reductions in another, may not be adequate to cover agriculture: there is a danger that well quantifiable and secure emissions from industrial installations are offset by very uncertain and highly varying reductions from agricultural projects.

27. The question on how to best **design mitigation policy for agriculture** remains open. As offset mechanisms are problematic, governmental regulation, prescription of certain practices or technical specification, or certain environmental taxes or subsidy schemes could be used. Such discussion is taking place in the context of the emerging specification of Nationally Appropriate Mitigation Actions NAMAs, a still undefined term. In organic agriculture, trade-offs between food production and other ecosystem services are minimal. Thanks to its multi-output character, it is especially appropriate for NAMAs as it delivers mitigation and adaptation benefits together with biodiversity gains. Supporting OA can be a more effective and efficient part of a set of policies than other, more targeted, single-goal policy instruments (Schader 2009), especially when the already existing certification scheme can be used for the reporting. It should therefore be assured that any rules for further specification NAMAs are not at odds with systemic agricultural practices, such as organic agriculture. It will, however, require also within the organic agriculture research, an increased focus, innovation and extension on management practices that favour both mitigation and adaptation.

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