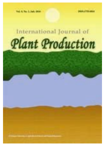

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A brief discussion on energy use and greenhouse gas emmision in organic farming

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Abstract

Organic farming has become increasingly popular in the world. This is mostly attributed to escalating consumer concerns over the impacts of pesticides and chemical fertilizers on human health as well as growing concerns over environmental pollution derived from modern agricultural practices, such as rising greenhouse gas emissions and water contaminations. But does organic farming actually displace the environmental impacts commonly associated with conventional agriculture? In this article, we analysed the recent results of environmental impacts from organic farming. The aim was to fill the gap in assessing organic farming's relationship to climate change and evaluating sustainability of this system with a minimal energy and environmental damage over time. Despite the efforts of recent years, there is still considerable room for the environmental optimisation of organic farming systems. The lower, similar or higher impacts of organic farming, depended on crop types, site effects and differences in management intensity. The conclusions here are exploratory and act as a call to action to natural scientists to further explore how organic farming functions. Feeding the growing world population under conditions of restricted land for agricultural cultivation, restricted natural resources and changing climate demands new and innovative solutions. These solutions require the agricultural community, to address agricultural systems from a perspective of increasing the productivity per area with lower external inputs and enhancing resource use efficiency without negative effects on crop yield and system sustainability.

Keywords: Eco-efficiency; Low inputs systems; Renewable resources; Global warming.

Introduction

Contemporary research sugggests that humanity is over-exploiting the environment, driving global climate change, eutrophicantion, degradation of ecosystems and biodiversity loss (Rockstrom et al., 2009). The diversity of farmed crops is declining, the resilience of agroecosystems to ahthropogenic perturbations is eroding and the environmental degradation from agriculture is widespread (Norberg and Cumming, 2008; Rabotyagov et al., 2014). At the same time, the world's human population is projected to grow from 7.2 billlion people to 9.6 billion by 2050 (UN special report, 2012). As a consequence, organic and low-input systems use of mechanical and biological methods in enhancing resource use efficiency without negative effects on crop quality and system sustainability have been developed as safer alternatives (Wise, 2013; Hatfield and Walthall, 2015).

Since as early as the 1940s organic farming has been an alternative to the industrialized methods used in mainstream agriculture, promoting agricultural practices that are more in line with natural ecology, less intensive on soil and more humane toward animals (Guthman, 2004). Organic farming is a form of agriculture that relies on techniques such as crop rotation, compost and biological pest control to maintain soil productivity and control pests, which avoids the use of synthetic fertilizers and pesticides (Maeder et al., 2002; Helander and Delin, 2004; Jørgensen et al., 2005). FAO/WHO (1999) defines organic farming as a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity. FAO promotes organic farming as an alternative approach that maximizes the performance of renewable resources and optimizes nutrient and energy flows in agroecosystems. Therefore, organic farming is considered a promising solution for reducing environmental burdens related to intensive agricultural management practices (Nemecek et al., 2011) and is gaining interest worldwide due to its environmental benefits compared to conventional, intensive agriculture (Sandhu et al., 2010; Maeder et al., 2002).

The attendant benefits of organic farming, such as the positive effects on soil fertility, biodiversity maintenance and protection of the natural resources of soil, water and air have been extensively investigated (Eriksen et al., 1999; O'Brien and Leichenko, 2000; Montemurro et al., 2004; Moller, 2009). Farmers are now continuously requested to increase crop yields while at the same time preserving the environment by reducing the dependency of agriculture on external, non-renewable fossil energy and reducing the emission of greenhouse gases (Bailey et al., 2003; Bechini and Castoldi, 2009). Sustainable practices must be understood as an additional driver of environmental impacts, but only insofar as they relate to environmental impacts themselves. However, there is no comprehensive evaluation on the comparison of organic and conventional production in energy flow (renewable and not renewable) along with gas emissions. Both are very important issues for sustaining the equilibrium of the environment.

In this article, we addressed recent advances in organic farming from the aspects of energy use and greenhouse gas emmision with an aim to fill the gap in assessing organic farming's relationship to climate change and evaluating sustainability of this system with a minimal energy and environmental damage over time.

Energy balance and uses

Energy balances for agricultural systems have been studied since the 1970s (Pimentel et al., 1973; Berardi, 1978). Energy inputs and outputs are important factors affecting the energy efficiency and environmental impact of crop production, which provide an important view of the agriculture as a user and producer of energy (Risoud, 2000).

The energy efficiency of a productive system can be measured as net energy, energy output/input or energy productivity. Net energy increases as long as the energy output per unit energy input increases (Rathke et al., 2007). It should be maximum when the availability of arable land is the limiting factor for plant production (Hulsbergen et al., 2001) or when the land is used to produce renewable energy (Kuemmel et al., 1998). The review by Zentner et al. (1998) indicates that the 'net energy produced' is a more desirable measure of energy efficiency than the output/input ratio since the absolute quantities of energy to calculate net energy are stated. This variable can therefore be used to determine the optimum intensity of land and crop management from an ecological point of view (Hulsbergen et al., 2001) and is considered more appropriate for the comparison of alternating crop production systems since it does not depend on the calorific content of the product (Hernanz et al., 1995).

The efficiency of energy use can be increased by reducing inputs such as fertilizer and tillage operations, or by increasing outputs such as crop yields (Swanton et al., 1996). In some cases, a reduction in energy inputs entails a proportional reduction in crop yield. In such cases energy efficiency is not significantly affected (Risoud, 2000; Bailey et al., 2003). In some modern, high-input farming systems, crop yields have improved continuously as a result of increasing inputs of agrochemicals (inputs of fossil energy) and the growth of more productive cultivars (Hulsbergen et al., 2001). Other studies report reductions in energy efficiency due to energy inputs increasing faster than energy outputs, the result of a growing dependency on inorganic, non-renewable resources (Weseen and Lindenbach, 1998; Gundogmus, 2006; Gundogmus and Bayramoglu, 2006).

Dalgaard et al. (2001) proposed that a conversion to organic farming would increase energy efficiency of Danish agriculture. The machinery operations can use up to twice as much energy on organic than on conventional farms (Lotjonen, 2003). However, the energy efficiency of an agrarian system, varies considerably depending on farm location (weather, soil type), crop rotations, the use of fertilizers, etc. (Bonny, 1993; Rathke et al., 2007). This shows the importance of determining energy balances for all pedo-climatic conditions (Pacini et al., 2003).

Zentner et al. (2004) found that net energy output showed a behaviour generally similar to that of energy output. The results by Moreno et al. (2011) are only partially in agreement with this, since the organic system produced the lowest energy outputs.

Moreno et al. (2011) found that, the energy ratio in the organic system was 2.3 times higher than those seen in conventional and conservation with no tillage systems and, for the whole period, the organic system produced 5.36 units of energy output for every one unit of energy input spent, while the conservation and conventional systems returned 2.35 units. They thus proposed that conventional or conservation (no tillage), appear to be little efficient regarding energy, while organic (low-input) farming would appear to be suited better to the environmental conditions of Mediterranean drylands, more than doubling the energy efficiency (output/input) of the above agrochemical systems and offering a sustainable production over time with a minimal energy input. These results were in concordance with Risoud (2000) and Klimekova and Lehocka (2007), a result of lower crop yields.

However, Jørgensen et al. (2005) observed that the energy productivity of a barley crop was only marginally lower under organic management than under conventional management, since the yield and energy requirements in the former system were reduced in the same proportion as in the latter.

In relation to output/input ratio and energy productivity, it is important to take into account that the interpretation of the results could lead to misleading conclusions when inputs are reduced (small denominator) but at expense of soil erosion, soil organic matter decrease and overall sustainability, aspects not shown in the organic (low input) management, as previously exposed. Alaphilippe et al. (2013) found that organic farming systems were generally less energy consuming compared with low-input and conventional systems when results are expressed per ha year, but the opposite was displayed, when expressed per kg year commercial fruits.

Efstratios et al. (2015) compared organic and conventional olive groves relative to energy use and found that fuel and transportation were the highest energy inputs for both farming systems, while, harvesting nets, machinery and labor were low. Hemmati et al. (2013) found that, for Iranian olive groves, chemical fertilizers had the highest contribution in energy inputs (63.2%) followed by electricity (20.8%). In other studies concerning other crops, the major energy input was either fuels or fertilization or electricity (Litskas et al., 2011; Zafiriou et al., 2012; Mohammadi and Omid, 2010; Mobtaker et al., 2012; Mousavi-Avval et al., 2012). Guzmán and Alonso (2008) stated that organic growing olive trees had greater non-renewable energy efficiency than the conventional ones. Williams (2006) analyzed the life cycle impacts of conventional and organic wheat, oilseed rape, potatoes and tomatoes and found that while organic used less energy than conventional agriculture on average, due to organic avoidance of synthetic nitrogen, it was offset by lower organic yields and higher energy requirements for field work.

Energy return on investment (EROI), the ratio between the energy harvested from an energy source and the energy that went into the energy harvesting process (Murphy et al., 2011), has been studied to some extent (Pimentel, 2009; Johnson et al., 2007). In Marocco and Turkey conventional and organic sugar beet production has been shown to have EROIs of 4.14 and 25.75, respectively (Mrini et al., 2002; Erdal et al., 2007). Atlason et al. (2015) investigated the EROI of three farms that produce sugar beets and other products such as wheat, onions and potatoes. They showed that the conventional farms produced in total two to three times the amount of sugar beet than the organic farm but also had more productive land. However, by comparing the EROI (using energy allocation) per hectare, the organic farm (EROI of 0.17) performs better than conventional farm (EROI of 0.12). If looking at the amount of energy from only sugar beet against the amount of fossil fuel used, the organic farm delivers 37.7 MJ for every MJ used of diesel and conventional farm delivers 12.4-13.4 MJ. After allocating energy usage between the sugar beet production and co-products using mass allocation, the organic farm delivers an EROI of 13.4, while conventional farm delivers 31.5. However, when allocating proportionally according to energy output, the organic farm delivers an EROI of 11.1, while conventional farm delivers 18.35. Even though organically produced sugar beet showed lower EROI than conventionally grown, there might be a possibility to reach such goals using organically grown sugar beet, greatly avoiding the use of fossil fuels in a portion of the production chain.

York (2012) found that the increased presence of non-fossil energy sources, such as hydro and wind power, only minutely displaced fossil fuel use on a global level. He concludes that ‘‘the shift away from fossil fuel does not happen inevitably with the expansion of non-fossil-fuel sources, or at least in the political and economic contexts that have been dominant over the past 50 years around the world’’. It is inevitable, that in the near future, finite natural resources such as fossil fuels will reach that point (Guilford et al., 2011). Therefore, for society to maintain agricultural growth and to power its industrial processes, it is essential to have access to high EROI resources.

Carbon sequestration and greenhouse gas emissions

Global warming potential, expressed in kg CO_2-equivalent including carbon dioxide, methane and nitrous oxides in the air compartment at a global scale, stemed from the use of energy resources and nitrogen fertilizers (IPCC, 2014). Organic farming, having low inputs, may contribute in diminishing energy inputs through the production of energy-smart food (Guzmán and Alonso, 2008; Michos et al., 2012; Ghorbani et al., 2011) and conduces to climate protection, to environmental problems reduction, such as greenhouse gas emissions and to natural resources degradation restriction (Litskas et al., 2011; Zafiriou et al., 2012; Bundschuh et al., 2014; Alonso and Guzmán, 2010).

Organic farming practices have been found to lead to carbon sequestration (Soil Association 2012; Govaerts et al., 2009), a process by which atmospheric carbon dioxide is absorbed by plants through photosynthesis and stored as carbon in biomass and soils (FOA, 2011). Additionally, organic farming has been found to have larger sinks for carbon dioxide in soil compared to conventional agriculture due to its higher rates of biomass levels and lower rates of soil respiration (OECD, 2003). In an analysis of 68 case studies that dealt with carbon sequestration under conventional and organic farming, Leifeld and Fuhrer (2010) concluded it was premature to assert that organic farming yielded higher benefits in this specific area. Furthermore, the authors found that the advantages of organic farming were largely determined by disproportional application of organic fertilizer compared to conventional farming.

Perennial crops under organic management exhibit higher soil carbon sequestration than annual crops (Kramer et al., 2006; Macrae et al., 2010), but the importance of this phenomenon to mitigate this impact category is still highly discussed among the research community and requires more knowledge (Powlson et al., 2011). Alaphilippe et al. (2013) found that soil carbon content remained constant in both organic and conventional system over the 4 years of the study. Such missing information raises scientific questions to answer these specific needs and might also open potential optimization of the production systems, through work on these gaps of knowledge.

Casey and Holden (2006) found organic Irish suckler-beef production had lower emissions of greenhouse gases than conventional production per area and per product unit. Organic apples had a lower global warming potential (Milài Canals et al., 2001), while various other products showed higher emissions per product unit (Williams et al., 2006). A clear difference in favour of organic farming was often found for the impact categories ecotoxicity and human toxicity (Mattsson and Wallén, 2003; Nicoletti et al., 2001), which is explained by the ban of synthetic pesticides in organic farming.

Proietti et al. (2014) studying the carbon foot print of an Italian intensive olive grove found that the annual average value for the first 11 years of CO_2-equivalent emissions was 1.507 Mg ha^{-1}, having the highest value during the first year due to the many mechanized operations and fertilization. Robaina-Alves and Moutinho (2014) stated that the use of N per cultivated area (i.e. fertilizers) was an important factor to gas emissions increasement, while a decreasement was observed when labor productivity increased. Thus, the implementation of best management farming practices using renewable energy inputs which lead to lower gas emissions could be used as a protection aid for sensitive areas (Liu et al., 2010a; Kavargiris et al., 2009; Liu et al., 2010b).

Many field trials worldwide show that organic fertilization compared to mineral fertilization is increasing soil organic carbon and thus, sequestering large amounts of CO_2 from the atmosphere to the soil. Lower greenhouse gas emissions for crop production and enhanced carbon sequestration, coupled with additional benefits of biodiversity and other environmental services, makes organic farming a method with many advantages and considerable potential for mitigating and adopting to climate change (FOA, 2011).

McGee (2015) found that rises in certified organic farmland 2000–2008 are correlated positively with greenhouse gas emissions from agricultural production, suggesting that certified organic farming is currently working to increase emissions of greenhouse gases. These results align with the sentiment of Venkat (2012), who argue that organic farming practices applied at the scale of conventional agricultural production emit more greenhouse gas than conventional farming due to its lower yields and its reliance on machinery to maintain crops. Similarly, Lefeild and Fuhrer's (2010) caution against claims that assume organic farming is a ''more sustainable'' form of agricultural production in regards to climate change because a link has yet to be established between organic farming and its higher levels carbon sequestration.

Recent analyses have also looked comparatively at organic and conventional agricultures' relationship to climate change through life cycle analysis (LCA). LCA, also named cradle-to-grave analysis, allows an objective and general comparison of the analyzed systems (Milài Canals et al., 2006; Mouron et al., 2006) and is suitable for comparing production systems (Haas et al., 2001). Williams (2006) found that organic tomatoes emitted 30% more greenhouse gases than conventional agriculture mainly as a result of lower yields. Similarly, Pelletier et al. (2010) studied a hypothetical national transition from conventional to organic production of canola, corn, soy and wheat in Canada. They found that organic production would generate 23% lower greenhouse gas emissions than conventional production, without considering soil carbon sequestration. This difference was almost entirely related to the production of synthetic nitrogen fertilizers for conventional farming. In an analysis of the life cycle patterns of 12 conventional and organic crops in California, Venkat (2012) found that greenhouse gas emissions from organic production were on average 10.6% higher (excluding walnuts as an outlier) than conventional production. They cited lower yields and higher on-farm energy use in organic farming, the production and delivery of large quantities of compost in some organic systems and the fact that emissions from the manufacture of synthetic fertilizers and pesticides used in conventional farming are not large enough to offset the additional emissions in organic farming as reasons for this phenomenon.

Though some analyses above point to organic farming being associated with higher levels of greenhouse gas emissions, the global consensus still recognizes organic farming as a way of reducing anthropogenic climate change. This can be seen in the following statement by the Food and Agriculture Organization of the United Nations (FAO, 1999): The emissions in conventional production systems are always higher than those of organic systems, based on production area. Soil emissions of nitrous oxides and methane from arable or pasture use of dried peat lands can be avoided by organic management practices.

The question of whether or not organic agriculture is suppressing greenhouse gas emissions is tangled within a broader question of environmental sustainability and suggested that certain forms of sustainable production are not necessarily reductive to more environmentally hazardous ones (McGee, 2015). Therefore, the task at hand for ecological scientists is to further understand specific organic practices' and their relationship to greenhouse gas emissions, as well as other forms of environmental degradation, in the hopes of identifying the most essential practices for sustainable organic production.

Conclusions

The sustainability in production systems requires knowledge of energy use in agriculture. Environmental and energy analysis of a production system could be combined to lead to the best management practices needed to be applied (Michos et al., 2012; Kaltsas et al., 2007; Kizilaslan, 2009; Djomo et al., 2013; Astier et al., 2014). Introducing the use of renewable energy inputs and leading to lower gas emissions could be used as a tool for sensitive areas to apply best organic farming practices. Additionally, they support a mechanism to quantify improvements (balance between environment and agriculture) that may influence energy inputs leading to more efficient production techniques.

Organic farming systems can probably contribute in reducing production costs, increasing energy efficiency, but are limited in reducing particular forms of environmental degradation, which is in general either lower or superior in environmental terms. Whether organic farming is really more environmentally friendly than integrated production requires a differentiated analysis and depends on the following factors: (i) level of analysis (single crop, crop rotation or whole farm), (ii) considered function of the system and (iii) considered environmental impact (Nemecek et al., 2011). The main strengths lie in better resource conservation, since the farm relies mainly on internal resources and limits the input of external auxiliary materials. According to Pimentel (2009), there is not substantial dissonance between definitions among authors and organisations involved in organic farming. Thus, it cannot be said that the concept of organic farming is fully consolidated. There are several perspectives that offer different insights, may vary over time and are, not reconcilable. The core values of organic farming, as they are described in the IFOAM (2010), specifically the four principles of health, ecology, fairness and care. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Therefore, the challenge remains to understand how organic farming can grow, incorporate new actors and technologies and integrate global markets without losing internal coherence and without deeply departing from these core values. Improving eco-efficiency of organic farming needs to focus mainly on the outputs, i.e. higher yields of good quality should be achieved with the available (limited) resources, while care must be taken to keep a good balance of different management interventions and not to focus only on single measures. The study showed that despite the efforts of recent years there is still considerable potential for the environmental optimisation of organic farming systems. The conclusions here are exploratory and act as a call to action to natural scientists to further explore how organic farming functions.

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