

Short communication

Organic agriculture cannot feed the world

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1. Introduction

Organic agriculture (OA) currently occupies 0.3% of agricultural land, mostly in developed countries. This land is farmed according to rules administered by various OA-regulating associations that, in the case of crops, disallow the use of most inorganic compounds for crop nutrition, synthetic compounds for pest, disease and weed control, and more recently, genetically modified cultivars. The rules also encourage rotations and intercrops to build soil fertility, improve crop nutrition, and to control or limit production problems associated with pests, diseases, and weeds. These latter aspects of OA are practiced much more widely outside OA, but those systems, here referred to as conventional agriculture (AG), vary enormously in range and amount of 'OA-prohibited' inputs. They include, for example, many farms in developing countries where agrochemicals are not used because they are either not available or are too expensive.

The acceptance of OA in developed countries is increasing, *albeit* more slowly than in the previous decade, driven by consumer concern for food and environmental safety and supported by premium prices that consumers will pay for OA-labelled products. The biggest markets are in USA, where 0.3% of agricultural land is devoted to OA, and Europe with 3.4%, where additional subsidies are available. At the same time, AG is also responding to the same food and environmental safety concerns with alternative labels developed by food retailers based on 'good farming practices' for products from production systems that integrate the use of agrochemicals with biological processes. The same trends are evident in developing countries too, but the markets for labelled products are smaller and price premiums depend on the access they give to export markets in developed countries.

An important issue to the acceptance of OA is found in the question of its productivity. Existing analyses have put the carrying capacity of OA at 3–4 billion, well below the present world population (6.2 billion) and that projected for 2050 (9 billion). Those analyses (Buringh and van Heemst, 1979; Smil, 2001, 2004) are based on the performance of OA systems as practiced in C19 before the widespread use of inorganic fertilizers and when the world population was around 1 billion. They remain relevant to the present discussion, because advances in crop yield since those times have not changed the essential metabolism of plant growth and nutrient requirement to support it. A recent paper by Badgley et al. (2007) has reopened this debate by presenting an analysis purporting to show that OA cannot only greatly increase productivity in developing countries but could feed the entire world also. The paper, initially presented in May 2007 at the FAO Conference on Organic Agriculture, has received much attention in the popular press and science magazines, e.g. *New Scientist* (2007). OA does not need the ability to feed the world to contribute within agricultural production but this report provides some with justification to solve perceived and real production and environmental challenges in agriculture and food supply in a single step by large-scale transformation to OA. In this, the alternative development paths that resource-poor farmers of the developing world might take are a particular focus of attention. The conclusions of the study are, however, invalid because data are misinterpreted and calculations accordingly are erroneous.

2. A major overestimation of the productivity of OA

Badgley et al. (2007) estimate OA productivity by applying OA/AG yield ratios calculated from the literature to national food production statistics from the FAO database. For developed countries the ratios are dominantly between high-yielding crops well supplied with either organic nutrients (OA)

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or fertilizer (AG). The mean ratio is 0.91. For developing countries, in contrast, the ratios (mean 1.74) are obtained largely from comparisons of low-yielding crops that received either organic nutrients (OA) or little or no fertilizer (AG). In most cases, organic nutrients were from external sources. It is the inequality of inputs to crops grown below full nutrition that explains the different and high ratio (>1) in the developing country data. The authors, however, avoid that explanation, defend the comparison as valid with the unproven suggestion that OA is able to out yield AG ‘by eliciting different pathways of gene expression’, and rather focus on the low value of the ratio from developed countries. That outcome they explain results because many agricultural soils there ‘have been degraded by years of tillage, synthetic fertilizers, and pesticide residues’. Neither of those explanations can be identified, however, in the comparisons from developed countries. The authors have seriously misinterpreted the ratios for developing countries, but more importantly have misunderstood the applicability of those ratios to their subsequent calculations of the productivity of OA. Both contribute to major overestimation.

The calculation of productivity following large-scale transformation to OA is made in two ways. First, OA/AG ratios for developed countries are applied to entire world food production, and second, individual ratios are applied to developed and developing country food production, respectively. The first alternative, it is proposed, assumes AG in the developing world is equally well supported by fertilizer as the developed world, the second that it is not supported by fertilizer at all. The first alternative, unsurprisingly, estimates a reduction (5%) in total food supply (7% in crop production) and the second a 57% increase (43% in crops). The latter, it is concluded, is sufficient to feed a greater population than the current 6.2 billion. The conclusion is wrong because, quite apart from the error in the yield ratio itself, food production in developing countries is not achieved by OA. Agriculture there is dominated by conventional methods that currently consume 70% of total world fertilizer use (IFA, 2007). In other words the authors have applied an overestimate of the relative yield of OA in developing countries to a gross overestimate of its productivity there. If crop production by organic methods in the developing world were even 70% of current recorded value, then that combined with an yield ratio (1.74) that is substantially greater than a defensible maximum ($=1$), would lead to an overestimation of 250% in that calculation of productivity of OA.

So much for arithmetic, but there is another serious agronomic misunderstanding. The authors have failed to realize that any significant increase in OA from its current small base of world agricultural area (0.3%) will increase competition for limited organic nutrients. That in turn will reduce the beneficial impact of OA on the low-input component of agriculture in developing countries and increase the current disadvantage of OA in developed countries. Crop yields and/or cropped areas will fall as an increasing proportion of land is devoted to biological regeneration of fertility. The ratios will fall to values below the current estimate

for developed countries, further explaining why the method of calculation has seriously overestimated productivity of large-scale OA.

3. On the limited availability of organic nutrients

If large-scale conversion to OA were possible, where would the organic nutrients to support the high productivity required to feed a large and expanding world population come from? The second part of [Badgley et al. \(2007\)](#) seeks to confirm the conclusion of adequate productivity of OA by a parallel estimate of the potential of leguminous cover crops to provide the required organic N. A survey of published N-fixation rates and crop performance in legume rotations is used to establish equivalent N fertilizer contributions from such crops as 95 and 108 kg N/ha for temperate (developed) and tropical (developing) conditions, respectively. There is no space here to analyse the relevance of all the data that contribute to these estimates save noting that the mean values may be overestimates because of some obvious outliers and because the entries are not restricted to short-term cover crops as required by the analysis. At those high rates, however, the authors calculate that an additional legume cover crop added to 1362 Mha of cropped area (total world crop area less 170 Mha already in leguminous forage production) would provide 140 Mt N/year. Since this is substantially greater than the current annual worldwide N fertilizer use of 91 Mt (IFA, 2007), the authors used 82 Mt for their 2001 calculation, the ability of OA to feed the world is confirmed. Or is it? What are the limitations of this calculation?

In practice all existing cropland cannot be provided annually with N by an additional leguminous cover crop without significant disruption to crop area and production. Here, the authors demonstrate limited appreciation of crop ecology and agronomy. First, because much productive land already carries multiple crops. In needy places such as Bangladesh, for example, average cropping intensity is already 2.5/year. Second, because most land that now carries one crop or less each year does so for limitations of temperature or water supply that exclude the possibility of a second crop. In those places, legume cover crops could only be introduced in a 2-year cropping sequence. In others, for example southern Australia, cover crops could replace legume-based pastures now in rotations with crops ([Peoples et al., 2001](#)) but with an uncertain advantage to N gain. Farmers there, in a region where a significant proportion (70%) of N is provided by biological fixation, have shown no enthusiasm for that option. There are no current statistics to estimate the proportion of world current cropland that could accept an additional legume cover crop, but it is certainly much less than 100% as used by [Badgley et al. \(2007\)](#), and could only be increased significantly, in areas with suitable thermal regimes, by massive expansion of irrigation for which water is not available. If the authors had sought to explain why [Smil \(2001, 2004\)](#) was mistaken in his assessment of the small legume-based productivity of OA (maximum support for 3–4 billion) they would have been exposed to more realistic cropping scenarios than that they proposed.

4. An evaluation of the productivity of legume-based agriculture

Fortunately, there is a way to evaluate the legume-based cropping strategy proposed by [Badgley et al. \(2007\)](#). The provision of 100 kg N/ha fertilizer equivalent to all cropland would support, with inevitable in-crop losses to drainage and volatilisation of say 25% ([Crews and Peoples, 2004](#)), the production of 4170 kg crop dry matter/ha at 1.8% N. That amount of crop growth would, with a creditable harvest index of 0.4, establish an N-limited cereal yield of 1.7 t grain/ha, sufficient over 1362 Mha and allowing 10% for storage losses and seed for the following crop, to provide an adequate diet for 4.2 billion using the Standard Nutritional Unit (SNU) of 500 kg grain equivalent/person/year ([Loomis and Connor, 1992](#)). If instead, 50% of cropland could only support cover crops in 2-year rotations, then production would support 3.1 billion, comparable with the estimate of 3.2 billion made by [Smil \(2001, 2004\)](#).

The issue of legume rotations for the biological regeneration of fertility emphasizes, as stressed earlier, why OA/AG yield ratios used in the previous calculations must fall substantially under large-scale transformation to OA. The cropping strategy proposed by [Badgley et al. \(2007\)](#), although unrealistic in detail, properly presents crops as components of closed systems. Leguminous crops and pastures build up N fertility, non-legume crops extract it either directly or as applied green or animal manure, and the cycle continues. That is not, however, the sort of system from which the yield ratios used in the productivity assessment were calculated. Rather they were dominated by yields of individual crops for which organic manure was just another external input. In cropping systems, the entire area involved in production of grain crop, cover crop, pasture, and animals must be included in the calculations of productivity. It is this cost of biological N-fixation (land, labour, water) that most disadvantages OA relative to AG and suppresses the system production ratios well below unity. If a grain crop can be grown after a legume crop in 1 year then fertilizer may allow the growth of two grain crops. If legume and grain crops can only be grown in successive years, then successive grain crops are possible with fertilizer. This is exactly the issue that faces millions of resource-poor farmers in Asia where the yields required for survival can only be achieved by multiple food crops. How, for example in the rice–wheat system of south-east Asia and China could OA provide the quantity of N (300–400 kg/ha) to produce the required annual combined grain yields of 10+ t/ha.

5. Conclusion

A critical analysis of the nature and use of OA/AG yield ratios does not support the proposition that large-scale OA productivity would be sufficient to feed the world or that legume cover crops could replace N fertilizer use without disrupting current food production. There is, therefore, no newly established production frontier for OA so that those who use the conclusions of the study by [Badgley et al. \(2007\)](#) to

promote or support OA will have been misled and limited resources for research and development would be misallocated. The biggest losers are likely to be resource-poor farmers in developing countries. That organic nutrients can increase the now low yields of nutrient-limited crops is not in dispute. What is in dispute is the promotion of a transient OA solution as the sustainable solution when fertilizers, that can provide a complementary route to increasing yields now, will be essential for the high productivity that will be required in future.

6. A way forward

Transformation to OA is, of course, not only about N supply but rather the interaction of a number of social, environmental and economic concerns and outcomes. Important issues include maintenance of soil condition, provision of nutrients other than N, human labour, control of pests, diseases and weeds, product quality and safety, and minimizing off-site environmental effects. Surely now is the time, for unbiased analyses of alternative agricultural production systems in the search for optimal management solutions. The world needs a highly productive agriculture that can save as much land as possible for nature ([Waggoner, 1994](#)). There is much emphasis in AG to improve fertilizer formulations and use site-specific application methods, timing and amounts to optimise fertilizer use for production and environment. At the same time, crop nutrition, and not just N, is a critical issue in OA because there are few locations where sufficient quantities of organic nutrients are available. There is recognition within the broad reach of the OA movement that revised practices would be advantageous. There are proposals, on the one hand, to more closely align practice with low-input approaches to crop production ([Parrott et al., 2006](#)) and, on the other, a move to ‘replacement’ organics that allows fertilizer when essential. Such adjustments would remove much heat from debates as both ends of the farming spectrum seek to optimise inputs for productivity and environmental sustainability. This seems especially pertinent at a time when the enthusiasm for biofuel as a solution to energy security and climate change is set to revolutionize agricultural practice by seeking an additional productivity that, even for a small replacement of current liquid transport fuel, could easily outstrip that required now for food production.

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