Can organic agriculture sustainably feed the future world population?[1]

Introduction

Current agricultural production needs to be substantially increased (>60%) to meet the growing global demand for food and livestock feed for the projected ~9.7 billion population by 2050. Considering that >54% of the children in South Asia (including India) are malnourished, improved nutrition is an equally important component of food security. Hence, we need to ensure that the supply of nutritious food is adequate to meet the demand arising from the need for better health and nutrition of human beings globally.

Before the advent of industrialization in the 19th century, there was enough cultivable land, and sufficient food was being produced to feed the population. Soils were fertile, and there was no need of inorganic (synthetic) fertilizers. However, the cultivable land/capita is getting less, especially in Asia (about one ha per capita in India); soils are undergoing considerable erosion and are depleted of major plant nutrients. The situation is further complicated by events related to globalization and climate change.

While the adverse effects of modern farming with chemical pesticides and fertilizers on environment and human health are recognized, we also need to understand that organic agriculture is not a panacea, and a cure for all the ills of modern agriculture. There are reasons why organic agriculture alone, in its present form, will not be able feed the future global population. Organic agriculture (OA) is suitable in some agro-ecologies for some of the farmers, and there are niches where OA can be practiced profitably and sustainably. The challenge for current agriculture research and development practioners' is to amalgamate the best practices from OA and modern science-based technologies to develop sustainable agricultural practices (SAP) that can maintain increases in food production, while ensuring that the environmental impacts are positive. In this paper we use Organic Agriculture and Organic Farming interchangeably.

Organic Farming

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As per ancient literature, agriculture originated in the hilly regions of Caspian basin of West Asia and the adjoining Iranian Plateau, dating back to 7500-6500 BC. It moved eastward towards India and China via the Harappan and Vedic civilizations. Agriculture was practised in India and China for many centuries, as far back as 4000 BCE. Population pressure and increased frequency of famines forced people to look for alternatives, including chemical fertilizers and pesticides. Revival of organic agriculture began in the early part of the twentieth century in Europe and later in the United States, and subsequently in other continents.

There are many definitions of organic agriculture. Some people define OA as one that relies on use of farmyard manure, compost, and green manuring for adding nutrients to the soil (that eventually is taken up by plants) and the use of biological control or bio-pesticides to manage pests and diseases. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony.

As per literature reviews, OA has quite a few advantages:

(i) Enhancing crop diversity: organic farming involves multiple cropping, and it provides insurance against risks associated with weather (rainfall) and pest attacks, and provides a diversified food basket to the farming family. In addition, most organic farmers tend to cultivate landraces, thus enhancing crop varietal diversity.
(ii) Improving and sustaining soil health and fertility: Since organic farming involves addition of organic matter (green manure, compost, etc.) the rhizosphere is rich in microbial activity and helps in sustained release of nutrients and management of soil-borne pests.
(iii) Managing weeds: OA integrates agronomic management, and use of biological and mechanical interventions to manage pests (weeds, insect pests, and diseases).
(iv) Managing pests and diseases: Organic farming uses biological pesticides (plant-based), and bio-pesticides (derived from bacteria and fungi to manage the plant pathogens). These are benign and do not adversely affect either the ecology or human health
(v) Enhanced biodiversity: Naturally occurring biodiversity is reported to show improvement in organic farming, as a result of not applying herbicides and pesticides in systems used in OA.

However, there are a few disadvantages with organic farming:

(i) Crop productivity: One of the major limitations of organic farming is that yield/ha is low compared to traditional/commercial agriculture. Many studies have been reported, but the results are inconclusive. An FAO report in 2007 stressed that one could not feed the current population by organic farming, let alone the future projected increase in population.

(ii) Profitability: Profitability of OA is entirely dependent on price premiums offered to organically produced food. Since yield levels (at least in annual grain crops) in OA are limited on average to 80% (of modern agriculture yields) in developed countries and up to 60% in developing countries, farmers will profit only if the price premiums are good. For the individual farmer in developing countries, marketing of OA produce is difficult, because certification and traceability issues have not been standardized or are not being properly implemented.

(iii) Labour requirements: OA is an intensive system in terms of both labour and knowledge. The increased labour cost results in organic food becoming more expensive. OA will cease to be profitable, unless price premiums are commensurate. Many countries in Europe subsidize OA to support farmers who practice organic farming. If the subsidies are stopped, then profits disappear as well.

(iv) Environmental impact: Although organic products require less energy, they need more land. Organic farming leads to higher nitrogen leaching, nitrous oxide and ammonia emissions, compared to conventional farming.

If one analyses the organic farming practiced worldwide, the following can be summarized:

(i) most of the certified OA is concentrated in developed countries and it is very limited in developing countries and countries in transition;

(ii) OA is feasible mainly in countries where cultivable land is in plenty and farmers can follow the recommended fallows and crop rotations;

(iii) much of organic farming is practised in areas where soils are highly fertile and soil organic carbon content is very high;

(iv) organic farming is feasible and practical in perennial horticulture crops such as fruit orchards (apple, peach, orange, etc.), and plantations (coffee, tea, cocoa, coconut, etc.) that are commercial crops, where profits are high;

(v) farmers in areas with good and reliable rainfall are able to practice OA for annual crops, such as staple food grains and pulses; and

(vi) farmers in arid and semi-arid regions (characterized by degraded soils and low and erratic rainfall) cannot afford or risk applying external inputs (chemical fertilizers, pesticides, etc.) in the low-input, subsistence farming they practice normally.

In an article published in *The Hindu* (4 Oct 2016), the author (Mr. S. Raghu Mokkapati) says that "Organic farming promises a lot: it can reduce the detrimental effects of conventional farming while cutting input costs, fetch a premium price on produce, improve soil fertility, promote efficient use of water resources, and provide safe food for consumers. But having worked closely with 8,000 farmers, I know that the realities on the ground present a stark contrast to this Utopian picture". He further states that "organic farming is not an economically viable option for the smallholder farmers who make up 80 per cent of farmers in India; and pushing these methods on such farmers can actually do much more harm than good".

There are also issues related to organic certification and traceability, neither of which is feasible or practical for a majority of smallholder farmers. On the other hand, consumers are not sure whether the organic produce being sold in the market is really organic, since there are no testing protocols or standards if one wishes to check if the organic produce is genuine or not. *The Hindu* article (cited above) suggested that "there is a lot we can do to improve organic farming and reduce the impact on the environment without going fully organic, by providing options to farmers about safe food that will allow the use of limited and specified agrochemicals within the safe levels specified by public health organizations".

From these analyses we can infer that organic agriculture is feasible and profitable for some farmers in some agro-ecologies and under certain farming situations and contexts; and there is also a need to make organic farming more profitable and sustainable, applying advances in science and technology, so that the farming community can produce enough food to feed the future world.

Are Organic foods safe and tasty?

Claims of organic farming protagonists that that organic food tastes better are not fully supported by evidence. It is seems to be the people's perception of taste, rather than a fact that can be measured in well-planned experiments or by nutritional analysis. Nevertheless, truly organic foods have been shown to have little chemical/toxic residues, and thus they may be considered safer than those produced with intensive use of fertilizers and chemicals. At the same time, it must be noted that there is really very limited information on actual health benefits from the consumption of organic products. We do not know enough to say that organic food is better than conventional foods.

The concept of "Soil as a Bank of Plant Nutrients"

In order to practice OA profitably and sustainably, farmers require good soil fertility (soil organic carbon and essential macro and micronutrients), appropriate soil structure, and adequate soil moisture. Most of the drylands of the arid and semi-arid tropics of the world have degraded soils, with low soil fertility, high air and soil temperatures, coupled with low and erratic rainfall. Being poor, many smallholder farmers cannot afford external inputs and hence follow traditional farming practices (called organic-by-default) that are no different from what OA practitioners' term as organic farming.

A recent study from the University of Western Australia has reported that it is not feasible to maintain organic matter in soils with less than 600 mm rainfall and daily average temperatures of >15C. We need to be pragmatic and look at organic farming more holistically, and consider "Soils as a Bank of Plant Nutrients". When crops are grown on a given soil, large amounts of nutrients are removed from the soil. For example, on an average one metric ton/ha of maize (corn) crop is estimated to remove ~161kg of Nitrogen, ~66 kg of P205 and ~48 kg of K20. (See Table 1)

Table 1: Nutrient Removal Rates (Kg/Ton) of Three Grain Crops*			
Crop	N Removal Kg/Tonne	P205 Removal Kg/Tonne	K2O Removal Kg/Tonne
Corn/ maize	161	66	48
Soybean	63	13	23
Wheat	20	11	6

Source: George Silva (http://msue.anr.msu.edu/experts/george_silva), Michigan State University Extension, October 19, 2015

- *Converted from Pounds/ Bushel to Kg/ Metric Ton (1000 Kg).*
- *Note: These are only indicative figures given for comparison purpose only.*

These nutrients that are taken up by the crops (see Table 1) need to be replenished after every harvest to maintain a positive balance of nutrients in the soil. Organic manures, although essential to improve the soil physical and microbiological heath, contain only small amounts of major nutrients such as nitrogen, phosphorus and potash(see Table 2).

Table 2: Content of major nutrients (%) in various manures and fertilizers*

Manures/ Fertilizers	Farm yard Manure	Cattle Manure	Horse Manure	Sheep Manure	Chicken Manure	Urea	Single Super phosphate	Potassium Sulphate
Nitrogen	0.5-1.5	0.6	0.70	0.70	1.1	45-46	----	----
P2O5	0.4-0.8	0.15	0.30	0.30	0.80	----	16-22	--
K2O	0.5-1.9	0.45	0.60	0.90	0.50	--	--	50-53

*Source: Rodale's All-New Encyclopaedia of Organic Gardening, An Illustrated Guide to Organic Gardening, by Sunset Publishing, the Rodale Guide to Composting; and FAI: *Fertilizer Statistics, 2013-14. This table is for purposes of comparison only, and it amalgamates information from different sources.*

It is evident that most commonly used organic manures (mostly cow and sheep dung and farmyard manures) have less than 1% N compared to 45 % in Urea, < 1% P2O5 compared to 16% in Single Super Phosphate, and < 1% K2O compared to 50% in Potassium Sulphate. Based on an average of 0.5% N in manure, farmers' need to add ~9 tonne of organic manure to get the equivalent of 100 kg of Urea containing 46% N. Most farm families in the developing countries (with the exception of Sub-Saharan Africa) are not maintaining many cattle (bullocks, cows, buffaloes and sheep) during the last 2-3 decades. Hence the issue is availability of such huge quantities of organic manure to replenish the cultivated lands. Therefore, it is essential to supplement the nutrients (both macro and micronutrients) through the limited use of fertilizers to ensure that farmers are not over-mining the soils and making them barren over time. Hence, it is recommended that farmers need to provide a combination of proper amounts of both organic and other fertilizers to ensure better soil health and sustainability of crop production.

Implications

A recent review by Kirchmann et al. (2016) concluded that "cropping systems with lower intensity (e.g., organic systems) demand more land to produce the same amount of food. The key goal of intensified and sustainable agriculture is to increase yields with minimal environmental disturbances. This review provides evidence that systems based on scientifically verified best agronomic practices are superior over organic ones with respect to yield, nutrient leaching, greenhouse gas emissions and conservation of biodiversity".

As mentioned above, the current and future generations of farmers will need a pragmatic approach of nutrient management, based on soil analysis, to ensure the nutrient requirements of crops to achieve optimum yield levels, by following **"Sustainable Agricultural Practices"** (SAP). This is a modification of Resource Conserving Technologies (RCT)**,** and combines the principles of conservation agriculture and modern agriculture in a balanced way: (i) zero or minimum tillage, depending on the soil and climatic conditions;(ii) use of crop residues for soil cover and as organic manure; (iii) soil-test based application of nutrients (both macro and micronutrients) as needed by the soil and cropping systems; (iv) management of weeds using safe herbicides as necessary; and (v) management of pests and diseases (using a combination of biological methods, biopesticides and minimal use of chemical pesticides) to ensure that the crop is healthy and farmers do not incur crop loss. Since many of these practices are labour intensive, and farmers need to be well informed, there is on-going debate on whether these practices can be widely adopted in the smallholder farming systems and help in meeting global food and nutrition requirements.

Summary

Organic agriculture was practiced during ancient times. With burgeoning population globally, the demand for food was met by modern agriculture practices using external inputs (chemical fertilizers, pesticides, etc.). However, over-use of chemical fertilizers and pesticides resulted in ecological and environmental problems. This led to the OA movement in the US and European countries, and much later in many other countries. While OA has many advantages with regard to environmental concerns, we are of the opinion that it alone cannot feed the increasing world population, with the impending climate change scenarios. The researchers involved in agricultural research for development, policy makers, and the farmers need to join hands to develop a basket of technological options for **"sustainable agricultural practices"(SAP**), and thus empower farmers to choose appropriate farming practices that are suitable for their farms, agro-ecologies and economic conditions.

Way Forward

Disruptive technologies have brought in revolutions in information technologies (IT), and IT is impacting several other fields, including agriculture. Farming is also undergoing transformation with the advent of precision farming, aided by cutting-edge technologies such as GIS (geographic information systems), GPS (global positioning system), and GNSS (global navigation satellite system) There will be cheaper agricultural robots in the future, and farmers in developing countries can become managers of land instead of toiling in their fields. Agroponics technologies will help produce crops with much less water. Growing crops in the cities (vertical farming), and in controlled growth chambers, without soil or natural light is already becoming popular in some areas.

There is a need to take a holistic view of “soil as a bank of nutrients”. Farmers need to replenish the nutrients taken up by a crop every season, especially in the impoverished tropical and sub-tropical lands, since organic manures (FYM, compost, and other animal manures) contain only small quantities of nutrients, and they will be needed in huge quantities for crops to be grown successfully. But these organic manures are not readily available in required amounts. Hence, the needed macro-and micro-nutrients need to be supplemented based on soil test results. Using GIS-based software for geo-referenced soil fertility mapping helps scientists to make appropriate recommendations of manures, bio-fertilizers, composts, fertilizers, and fertigation. We need to harness the synergies of integrating the valuable ancient knowledge and wisdom of traditional agriculture with modern science-based technologies to meet the challenges of 21st century agriculture.

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