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Organic Farming

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Summary and Keywords

Organic farming occupies a unique position among the world's agricultural systems. While not the only available model for sustainable food production, organic farmers and their supporters have been the most vocal advocates for a fully integrated agriculture that recognizes a link between the health of the land, the food it produces, and those that consume it. Advocacy for the biological basis of agriculture and the deliberate restriction or prohibition of many agricultural inputs arose in response to potential and observed negative environmental impacts of new agricultural technologies introduced in the 20th century. A primary focus of organic farming is to enhance soil ecological function by building soil organic matter that in turn enhances the biota that soil health and the health of the agroecosystem depends on.

The rapid growth in demand for organic products in the late 20th and early 21st centuries is based on consumer perception that organically grown food is better for the environment and human health. Although there have been some documented trends in chemical quality differences between organic and non-organic products, the meaningful impact of the magnitude of these differences is unclear. There is stronger evidence to suggest that organic systems pose less risk to the environment, particularly with regard to water quality; however, as intensity of management in organic farming increases, the potential risk to the environment is expected to also increase. In the early 21st century there has been much discussion centered on the apparent bifurcation of organic farming into two approaches: "input substitution" and "system redesign." The former approach is a more recent phenomenon associated with pragmatic considerations of scaling up the size of operations and long distance shipping to take advantage of distant markets. Critics argue that this approach represents a "conventionalization" of organic agriculture that will erode potential benefits of organic farming to the environment, human health, and social welfare. A current challenge of organic farming systems is to reconcile the different views among organic producers regarding issues arising from the rapid growth of organic farming.

Keywords: agroecology, agricultural history, sustainable agriculture, regenerative agriculture, ecological agriculture, biological agriculture, biodynamic farming

Introduction

Organic farming is a holistic approach to sustainable agriculture that adheres to several core tenants (Dorais & Alsanius, 2015; Gomiero, Pimentel, & Paoletti, 2011; Heckman, 2006):

1. The farm is an integrated whole.
2. There is a fundamental relationship between soil, plant, animal, and human health; and soil organic matter is of primary importance to that relationship.
3. Farm management emphasizes ecological practices and restricts many inputs in order to protect and enhance natural biological cycles.
4. Farm management conserves and recycles on-farm resources as much as possible.
5. Decision makers maintain an awareness of the broader social and environmental impacts of agriculture.

Although based on observations made in nature and practices derived from traditional agricultural systems, the contemporary organic farming movement developed in response to dramatic changes in food systems. During the 20th century, the introduction of new, primarily chemical, agricultural technologies radically changed food productions systems (see "HISTORY").

Organic farming has diversified since the 1980's to include large business models and global trade. Regulations that set the minimum production standards for commercial organic farming are enforced by certifying bodies at the global, regional, national, and local levels. Consumer perception of positive environmental and human benefits of organic food has dramatically expanded the market since the 1980s, and organic farming is reported in 173 countries on over 40 million hectares of land (Willer & Lernoud, 2016). Despite this growth, organic systems represent just 1% of the land in agriculture globally; although this number is much higher in some countries (e.g., almost 20% in Austria) and in certain commodities.

In response to the perceived commercialization of the term "organic," these systems may be alternatively described as "biological," "ecological," or "regenerative" agriculture. Also, while minimum organic standards are considered too restrictive by many, others feel that they do not go far enough and have expressed concern that "conventionalization" has reduced the environmental benefits and long term sustainability of organic farming (De Wit & Verhoog, 2007). This article will focus on the history, core practices, and impacts of organic agriculture with an emphasis on ecology and the environment.

History

Organic farming is rooted in traditional agricultural practices, but its development has paralleled and responded to rapid changes in agricultural production systems occurring primarily in the 20th century. Consequently, it is appropriate to regard organic farming as the foundation of a modern agricultural and social movement that continues to evolve (Tomaš-Simin & Glavaš-Trbić, 2016). Important drivers for the development of organic farming include the introduction of chemical fertilizers after the First World War (WWI), new pesticides after the Second World War (WWII), and the international growth in demand for organic products after 1970.

The primary catalyst for the coalescence of the organic farming movement in the early 20th century was the optimization of the Haber-Bosch process leading up to and during WWI, which allowed for the fixation of atmospheric nitrogen (N) into ammonia. In a modern conversion of "swords" to "plowshares," this technology was primarily used to create munitions for the war effort, but after the cessation of hostilities was used to generate synthetic nitrogen fertilizer for farmers (Johnson, 2016). Synthetic nitrogen rapidly replaced traditional fertilizer inputs such as manure in some locations, including India where Sir Albert Howard worked as an agriculturalist for the British government. Howard was a plant pathologist who witnessed a decline in crop health that he linked to a decline in animal health, both of which he ultimately attributed to the removal of organic matter and humus from the system as traditional inputs were ignored in favor of synthetic fertilizer (Reeve et al., 2016). His observations led him to formulate the "Law of Return," which advocated for the return of organic matter removed from the system in the form of composted manure (Heckman, 2006; Howard, 1940). His recommendations for compost production were developed in part from traditional Asian agricultural practices that were described in the book *Farmers of Forty Centuries* (King, 1927; Paull, 2014).

While Howard was in India, the philosopher Rudolph Steiner presented a series of lectures in 1924 in Germany where he emphasized the importance of spirituality in the pursuit of agriculture and acknowledged the interconnectedness of all components of the farming system (Paull, 2011). His agricultural course was well received and proponents of his approach expanded his ideas, which resulted in the publication of Ehrenfried Pfeiffer's book *Biodynamic Farming and Gardening* in 1938, which provided a name for Steiner's approach to agriculture (Biodynamic) and articulated the concept of the farm as a living organism. It was from this "organismal" perspective that Lord Northbourne coined the term "organic" in his book *Look to the Land* in 1940 to describe various systems of agriculture that were being proposed as alternatives to "chemical" agriculture that was being advocated by government and industry, based on the successes demonstrated by early fertilizer trials such as the Rothamsted experiments (Jenkinson, 1991; Paull, 2014). Lady Eve Balfour further developed Northbourne and Howard's ideas in her book *The Living Soil* in 1943, and helped found the Soil Association of England (Tomaš-Simin & Glavaš-Trbić, 2016). Similarly, Jerome Rodale grew the popularity of the newly named movement in the United States with his Organic Farming and Gardening magazine, 1942.

After WWII, powerful new pesticides originally developed to control insect vectors of human diseases for soldiers were made available and rapidly adopted by farmers and the general public due in part to both the efficacy of the compounds as well as active promotion by government and industry (Epstein, 2014). In the early 1960s, Rachel Carson brought attention to both observed and potential negative impacts to the environment and human health from the new synthetic pesticides (Carson, 1963). Evidence suggests that the denial of valid safety concerns, and in some cases the vilification of those raising the concerns by members and supporters of the agricultural chemical industry, resulted in a persistent erosion of public trust (Epstein, 2014; Heckman, 2006). It is likely that this lack of trust is at least partly responsible for consumer preference of organic produce as safer for the environment and human health, as well as rejection of new technologies (e.g., transgenic organisms) as potentially harmful even in the absence of conclusive evidence that these claims are true (Dorais & Alsanius, 2015; Fromartz, 2007).

By the early 1970s, organic farming was a global phenomenon and in 1972 the International Federation of Organic Agricultural Movements (IFOAM) was founded. Also during this period the number of scientific studies focused on organic systems increased (Dorais & Alsanius, 2015). Prior to this period, "organic" was often synonymous with "local," but after 1980 this was no longer the case (Fetter & Caswell, 2002). To maintain consumer confidence in organic products, the development and harmonization of certification standards became a priority. Examples of these standards exist at the global

(IFOAM), regional (European Commission regulations), and national level (e.g., U.S. National Organic Program). Although differences exist among these standards, they share many of the same minimum requirements, which include but are not limited to an emphasis on ecological farming practices and exclusion of most synthetic fertilizers, synthetic pesticides, sewage sludge, and transgenic organisms. There are processes in place to develop equivalencies between systems in order to facilitate trade (Huber, Schmid, & Napo-Bitantem, 2011; Luttikholt, 2007).

In the early 21st century there has been much discussion centered on the apparent bifurcation of organic farming into two approaches: “input substitution” and “system redesign” (Campanelli & Canali, 2012; Campbell & Rosin, 2011). The “system redesign” model can be described as the larger social movement approach centered on ecological farming that characterized organic farming prior to 1970. The “input substitution” approach is a more recent phenomenon associated with pragmatic considerations of scaling up the size of operations and long distance shipping to take advantage of distant markets for organic products. While compliant with minimal organic standards, the import substitution approach may be characterized by intensive use of inputs and a reduced reliance on ecological farming practices such as cover cropping and rotations. Critics argue that this approach represents a “conventionalization” of organic agriculture that will erode potential benefits of organic farming to the environment, human health, and social welfare (Campanelli & Canali, 2012; De Wit & Verhoog, 2007; Jeavons, 2001; McGee & Alvarez, 2016). Others suggest that this binary description of current organic farming systems is largely artificial and ultimately not useful in trying to address pragmatic issues of increasing organic yields and facilitating the transition of large operations to organic production (Campbell & Rosin, 2011).

Ecological Farming Practices

Organic Matter and the Primacy of Soil

Soil quality and soil health are used interchangeably in agriculture to describe the capacity of the soil to support ecological functions that optimize plant growth, including nutrient mineralization, water-holding capacity, and disease suppression (Doran & Zeiss, 2000; Hepperly, Seidel, Pimentel, Hanson, & Douds, 2007; Reeve et al., 2016). Proper ecological function of soil is critical to support optimal plant growth and quality. Maximizing soil quality relies on carbon-rich amendments that will feed the biological processes, which make the largest contribution to soil health indicators such as water stable soil aggregation (a measure of good structure), carbon dioxide evolution (a measure of microbial activity), and organic carbon content (Delate, Cambardella, Chase, & Turnbull, 2015; Doran & Zeiss, 2000; Reeve et al., 2016). Increased soil biology could also contribute to bioremediation of pesticides in soils (Sabourmoghaddam, Mohamad Pauzi, & Dzolkhifli, 2015). The three primary strategies organic farmers use to build and maintain healthy soil are cover crops, compost, and reduced or minimal tillage (Condron et al., 2000).

Cover crops are plants that are grown primarily to promote soil health rather than for sale; they may also be referred to as “green manures” (e.g., nitrogen-fixing legumes) and “living mulch” depending on their primary purpose. Cover crops are often planted as a rotation between food crops to break pest cycles, conserve topsoil, add organic matter, and suppress weeds. Cover crops are preferable to a weedy fallow because they typically produce more biomass than weeds, are easier to control, and do not contribute to the weed seed bank. Cover crops contribute relatively high amount of biologically active carbon when incorporated, and the additional ecological benefits they provide make them preferable in many ways to compost (Blanco-Canqui et al., 2015; Wang, Radovich, Pant, & Cheng, 2014).

Compost applications may affect soil properties important in crop production, such as pH, organic matter content, and cation exchange capacity, often in a more persistent manner than fresh residues such as cover crops (Magdoff, 1993). Also, compost applications affect plant growth by influencing soil microorganism populations including soil fungi, total bacteria, and actinomycete populations (Sivapalan, Morgan, & Franz, 1993). Soil biological activity supplied and stimulated by compost applications can significantly enhance disease suppressiveness in soils through two mechanisms: “general” and “specific” suppression (Hoitink, Gardener, & Miller, 2008). General suppression refers to the inability of soil pathogens to be effective; this is because of competition for resources by a diverse and active soil biological community. Specific suppression or “antagonism” involves interactions between potential pathogens and specific populations in the soil microbial community that reduce or eliminate virulence in the potential pathogen. Compost applications to pesticide contaminated soil may improve plant growth, enhanced microbial activity, and resulted in degradation of persistent soil pesticides with respect to un-amended soil (Liu & Cole, 1996).

Intensive tillage, promoted by Jethro Tull in in the early 1700s, has been widely adopted in agriculture in part because of its short-term benefits that include promotion of nutrient mineralization and effective weed control (Magdoff, 1993). These benefits come at significant soil costs, most notably degradation of organic matter and reduced resiliency to erosion pressures (Baveye et al., 2011). Reduced tillage is a strategy that has demonstrable benefits to soil quality, and it can take many forms, from a simple reduction in cultivation intensity to avoiding any disturbance to the soil (no-till). There has been limited adoption of reduced tillage by organic farmers despite the potential benefits to soil health primarily because of potential and observed loss in yield attributed to greater weed incidence and lower nitrogen mineralization (Cooper et al., 2016; Halbrendt et al., 2014). In order to reduce the intensity and frequency of cultivation on their farms, organic producers will use cultivation techniques that avoid inversion of their soils. Organic farmers also integrate strategies such as cover crops and other cultural practices to suppress weeds since there is no organic-compliant substitute for glyphosate used to control weeds in conventional no-till systems (Peigné et al., 2016).

Food Quality

Organic certification relates to how the produce is grown but makes no claim as to the quality of the product. Nevertheless, public perception that organic produce is better for consumer health than conventional produce has been a primary driver of the international growth in organic produce, as well as meat, sales (Diaz-Sanchez, Moscoso, Santos, Andino, & Hanningn, 2015). This is based largely on two assumptions:

1. Pesticide residues are lower or absent in organic produce.
2. The nutritive quality of organic produce is intrinsically higher than other produce.

Although there is some evidence that organic and non-organic produce can differ measurably in some of these quality indicators, there is no conclusive evidence that organic produce is in fact better for human health (Jensen, Jørgensen, & Lauridsen, 2013). Also there is some concern (but little evidence) regarding greater risk of microbial contamination in organic produce. Overall, researchers in this field generally conclude that it is more important that the public increase their consumption of fresh fruits and vegetables regardless of whether these are certified organic or not (Desjardins, 2016).

Pesticide Residues

The pesticides used in organic agriculture are a limited subset of those allowed for use in non-organic systems. As may be expected, pesticide residues are typically absent or lower on certified organic produce than in non-organic produce (Barański et al., 2014;

Desjardins, 2016). It is important to note that when detected pesticide residues in non-organic produce are usually low (below minimum reporting limits) and short-term health risks considered negligible, while long-term risks are not known but assumed to be low (Blair, 2012). Consumers who purchase certified organic produce primarily for the reason of avoiding possible residues despite the lack of evidence of harm may simply be “opting out” of what they view as an “on-going social experiment” to evaluate the potential risk of long-term, low-level exposure to pesticide residues (Fromartz, 2007).

Nutritive Value

Numerous reviews of the literature evaluating quality differences between organic and conventional produce have reported significantly variable (and in some cases contradictory) results. However, certain trends are evident: organic produce tends to have lower protein and nitrogen content and higher polyphenol concentrations per unit dry weight than conventional produce (Barański et al., 2014; Desjardins, 2016; Dorais & Alsanius, 2015). The concept of *terroir* is used to describe the significant influence that living (biotic) and non-living (abiotic) components of the crop environment can have on the chemical foundation of taste, aroma, and human health potential, and it supports the possibility that crops grown in different environments may have measurably different chemical composition (Radovich, 2010). In this case, both lower protein concentrations and higher polyphenols are thought to be linked with lower available nitrogen in organic systems, and it is hypothesized that higher pest pressure in organic systems also contributes to higher polyphenol levels (Orsini, Maggio, Rouphael, & Pascale, 2016; Pant, Radovich, Hue, Talcott, & Krenek, 2009). However, the potential impact on human health provided by the slightly higher levels (5%–15%) of polyphenols reported in organic produce are not known, especially given the fact that a small proportion of that increase is expected to be absorbed by the consumer (Orsini et al., 2016). Nevertheless, it is important to note the environmental dependence of crop chemical composition in the agroecosystem.

Microbial Contamination

Manure use is not exclusive to organic farming, but manures are more commonly used in organic production than in other farming systems and are an obvious source of potential microbial contamination (Blair, 2012). Organic standards attempt to mitigate risk of contamination by requiring active composting of manures under high temperatures, or application of un-composted (raw) manure 90 to 120 days prior to product harvest and actual risk of contamination has been determined to be low (Dorais & Alsanius, 2015; Köpke, Krämer, & Leifert, 2007). The exclusion of many effective fungicides from organic farming has led to some concern of myctoxin contamination, especially in organic grains; however, risk of mycotoxin contamination is more closely associated with farm size (bigger farms = greater risk), and risk associated specifically with organic systems is considered low (Blair, 2012; Köpke, Thiel, & Elmholt, 2007).

Environmental Impact

Organic farming may have the potential to reduce the negative impacts on the environment often associated with agriculture by virtue of a reduced reliance on external inputs, an increased emphasis on resource recycling, fewer potential pollutants introduced into the environment, and enhanced ecosystem biodiversity (Raviv, 2010). Some of these potential benefits include reduced greenhouse gas emissions and improved water quality.

Carbon sequestration in organically managed soils can be considerable, and organic farming has the potential to mitigate climate change through reduced carbon containing greenhouse gas emissions from crop systems (Bhattacharya et al., 2016; Campanelli & Canali, 2012; Delate et al., 2015). Lower nitrogen levels typically observed in organically managed soils are linked to lower nitrous oxide emissions from these systems, although this does not hold true for organic animal production (Gomiero et al., 2011; Singh & Strong, 2016; Tuomisto, Hodge, Riordan, & Macdonald, 2012).

The largest measurable difference in environmental impact between organic and conventional systems has been in water quality, particularly with regard to reduced potential for nitrate pollution. Nitrate adulteration of water resources has significant implications for human and ecological health. Excessive nitrate consumption may cause methemoglobinemia (Blue Baby Syndrome) in infants resulting from the reduction of nitrate to nitrite that reacts with hemoglobin to form a substance (methemoglobin) that does not bind and transport oxygen to tissues (Straub, 1988). Estuarine and near-shore marine ecosystems are also sensitive to excess nitrogen due to eutrophication. Nitrogen is the primary limiting nutrient in estuarine and coastal systems, and an influx of N via non-point source pollution may result in excessive increases in phytoplankton (algae) and macrophyte (larger aquatic plants) populations. This in turn may lead to the depletion of economically and ecologically important organisms and the interference with recreational use of water resources (Paerl, 1993).

When fertilizer applications are applied to supply the same total amount of nitrogen, the slow-release nature of organic amendments such as animal and green manures typically result in less potential for ground water nitrate contamination than mineral fertilizers (Cambardella, Delate, & Jaynes, 2015; Delate et al., 2015). This has been observed repeatedly and is a function of the fact that organic fertilizer amendments release nitrate more slowly than mineral fertilizers due to biological processes required to mineralize nitrate from organically bound nitrogen. However, mineralization potential is dependent on the ratio of total organic carbon to organic nitrogen (C:N) in the material; some fertilizers used in organic farming such as blood, feather, and meat meals have low C:N (< 10:1), and could release a majority of their total nitrogen in one crop cycle under favorable temperate and tropical conditions (Ahmad et al., 2016; Sullivan, Andrews, Luna, & McQueen, 2010). Therefore when applied at higher rates of application or in the absence of a crop to uptake mineralized nitrogen, nitrate leaching below the root zone and the potential for groundwater contamination may be considerable even when organic fertilizers are used.

Other input issues can influence the environmental impact of organic systems. For example, plastics are generally allowed in certified organic production with the restriction that they shall not be incorporated into the soil or allowed to decompose in the field, and they are frequently used for weed suppression, moisture retention, and other purposes. Although concerns have been raised regarding the potential of plastics to contribute to soil pollution through degradation, the most immediate concern is the large amounts of plastic waste potentially generated when the materials need to be disposed (Steinmetz et al., 2016). Use of plastic is an example of a practice that some associate with conventionalization of organic production. Many organic farmers choose to use un-composted plant residues such as straw or wood chips as mulch in lieu of plastic to reduce waste and add organic matter as it decomposes.

The Yield Conundrum

Evidence from multiple meta-analyses suggests that crop yields from organic systems are generally 10%–30% lower than conventional systems depending on a wide range of variables including crop and soil type, climate, grower experience, and many other factors (Delate et al., 2015; Dorais & Alsanius, 2015; Ponti, Rijk, & Ittersum, 2012). Lower yields are not always observed, and the yield differential between organic and non-organic may be much closer in fruit trees, other perennials, and legumes, as well as under drought conditions where the higher SOM in organically managed soils can provide greater water-holding capacity (Gomiero et al., 2011; Seufert, Ramankutty, & Foley, 2012). In some cases yields rebound after an initial decrease following transition from conventional to organic; this may be due to improvement in soil health indicators after multiple years of organic management, or improved grower competency over time as experience with organic production increases (Martini, Buyer, Bryant, Hartz, & Denison, 2004).

Lower yields in organic farming could potentially result in reduced profitability, but price premiums for organic products could offset potential losses, as demonstrated by multiple long-term comparisons of organic and conventional systems (Delate et al., 2015). Of greater concern is the fact that although the potential environmental benefits of organic farming systems are measurable when compared to conventional systems on a per unit area basis, when the same indicators are compared on a per unit product basis to adjust for lower yields, organic systems may have a more negative impact on the environment than conventional systems (Tuomisto et al., 2012). In an evaluation of multiple long-term trials in the United States, lower than optimal yields observed in organically grown grains and pulses were associated primarily with weed pressure and, in some cases, inadequate fertilizer (Delate et al., 2015). More intensive tillage, the use of plastic mulches and more intensive fertilizer applications may increase yields in organic farming but may also negate any potential environmental benefits derived from those systems. It is a conundrum not easily solved but may be addressed in part by approaches such as breeding crops under organic conditions for traits such a high nitrogen use efficiency and weed tolerance, as well as adjusting consumer diets to consume less meat (Lammerts van Bueren & Myers, 2011).

Conclusions

Although there has been valid critique of the potential sustainability of organic farming, it remains an important example of ecological agriculture that attempts to balance the need for productivity in the near term with a conservation of resources required to ensure those needs are met in perpetuity. Organic farming also serves as the foundation of a social movement that makes an indelible connection between ecosystem function, food quality, and human health. Despite this strong social component and the fact that not all claims made in the name of organic farming are conclusively supported by evidence, the ecological principles on which organic farming is based is grounded in good science. A current challenge of organic farming systems is to reconcile different views among organic producers regarding issues arising from the rapid growth of organic production, the call by some to increase yields and claims by others that the resulting "conventionalization" of organic erodes its value to the environment and the people it feeds.

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