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On-farm land management strategies and production challenges in United States organic agricultural systems

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ABSTRACT

The need to reduce the negative impacts of agriculture on the environment and the consumer demands for food produced without synthetic chemical inputs have led to organic agriculture production systems. The United States (US) commands about half of the market share of organic products worldwide and is home to half of the world's organic farmers, but limited information is available on trends of on-farm land-use practices and challenges in organic crop production systems. This study utilizes the agricultural production surveys from the United States Department of Agriculture (USDA) from 2008 to 2019 to investigate state and national trends in organic farm area, number, and sales, and to evaluate national trends in on-farm land-use practices and challenges facing US organic production. From 2008 to 2019, the number of certified organic farms, land area, and sales increased by 5, 6, and 12%, respectively. The use of green and animal manures is the most common land-use practice in certified organic crop production systems. The number of farms using the on-farm organic practices remained the same or increased steadily except organic mulch/compost which declined. However, all the practices declined proportionally, except rotational grazing which recorded an increase in 2019. The most significant primary challenges faced by certified organic farmers are related to regulations of organic practices and production costs which worsen over time. United States certified organic production has the potential for expansion in terms of farm numbers, land area, markets, and increased adoption of regenerative agricultural practices. However, for this to occur, efforts involving farm-level research and policy reviews with direct farmer involvement are needed to address these primary challenges facing organic farmers.

1. Introduction

Commercial agriculture today utilizes inputs from synthetic chemicals, both spatially and sectorally distant sources, which may increase agriculture's negative impact on the environment. The use of chemical fertilizers and pesticides can threaten species diversity, the environment, habitat, and risks to human health and welfare (Hodge, 1993). These threats have led to the emergence of organic agriculture, which is free of synthetic chemicals and emphasizes the use of sustainable and regenerative agriculture practices. The term "regenerative organic" was first coined by Robert Rodale to describe a holistic approach to farming that encourages continuous innovation and improvement of environmental, social, and economic measures (Rodale, 1983; Rodale Institute, 2014). The term regenerative agriculture is currently ambiguous in its definition, depending on the players involved (McGuire, 2018; Giller et al., 2021). But generally, organic agriculture represents a conservative and rehabilitative approach to farming and food systems, focusing on revitalizing the topsoil by increasing biodiversity, water use efficiencies, ecosystem services, carbon sequestration, and resilience to climate variability (McGuire, 2018; Giller et al., 2021; LaCanne and Lundgren, 2018). World organic agriculture grew from 11 million hectares in 1999 to 72.3 million hectares in 2019, with 35.7 million

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hectares in Australia followed by Argentina (3.7 million hectares) and Spain (2.4 million hectares) (FiBL, IFOMA-Organics International, 2021). The world organic agriculture market increased from US$ 17.7 billion in 2000 to 124.9 billion in 2019 with the US holding the largest market share of US$ 52.5 billion followed by Germany (US$ 14.1 billion) and France (US$ 13.3 billion) (FiBL, IFOMA-Organics International, 2021).

In the US, the organic farming movement started in the 1940s when Rodale provided information about synthetic chemical-free farming methods. He called it "non-chemical farming methods," based on the inspirations drawn from Sir Albert Howard, a British scientist who promoted the use of crop residues, green manures, wastes, and deep-rooted cover crops to recycle nutrients in the soil after spending some time in India and observing traditional farming systems (SARE, 2003). In the 1970s, the organic agriculture industry started growing rapidly, driven by an increase in environmental awareness of pollution and related consumer demands for food grown with few or no synthetic chemicals (Rigby and Caeceres, 2000). However, the industry suffered from a lack of standardized guidelines until the national organic standards were developed and implemented to facilitate interstate marketing. In 1990, the US Congress passed the Organic Food Production Act, creating a national standard for organic food and fiber production. The USDA was mandated to write the final rules and regulations, which were completed and implemented in 2002 (SARE, 2003).

Many definitions exist for organic agriculture, but for this study, we restrict our definition to the USDA organic standards. The US comprises half of the world-certified organic agriculture farms and sales value (USDA, 2016a). The USDA defines organic agriculture as "a production system that is managed to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity." (SARE, 2003). Certified organic agriculture promotes sustainable and ecological practices in agricultural systems such as cover crops, tillage, mulching, composting, plant selection, planting dates, green and animal manures, and crop rotations, which enhance biological activities for long-term soil and plant health (Rodale Institute, 2014; SARE, 2003; Reeve et al., 2016). For example, no-till and minimum tillage eliminate or reduce soil disturbance, which controls weeds, conserves moisture, reduces erosion, and increases soil microbial activities (Rigby and Caeceres, 2000). Green and animal manure are important sources of fertilizer for organic producers. Green manure is the incorporation of green plant materials into the soil for fertility recycling, while animal manure is the use of droppings from animals such as poultry, cattle, goat, sheep, and pigs for soil fertility management. Buffer strips are designed of permanent vegetation to intercept runoff, clean air and to prevent cross-contamination between fields (Gilley, 2005). Rotational grazing is another common practice in organic systems, in which divided sections are grazed individually and intensively while the remaining fields rest through paddocking (dividing the field into sections with fences) (Gerrish, 2004; Hodgson, 1990; Hopkins, 2000; Sharpe and Kenny, 2019). Other practices include plant selection and planting dates that help to manage pests and diseases in the organic fields. Plants are intentionally selected for their resistance to pest and disease or planted early to avoid coinciding with destructive stages of pest and disease (El-Shafie, 2019).

Though the above-mentioned on-farm land-use practices are key to the success of certified organic operations, comprehensive data were limited at all levels of organic production and their associated economics of production. This led to the first USDA national organic agriculture survey in 2008 as part of its 2007 five-year agriculture census. Data were solicited from organic farmers on all activities of their operations to support policy and decision-making of this sector. Nevertheless, comprehensive studies that highlight land-use trends are limited for on-farm practices and challenges faced by certified organic farmers in the US. Using USDA national agriculture census data from 2008 to 2019, this study investigates the variations and trends in on-farm land-use, organic markets, and primary challenges faced by organic producers in the US, and trends of the sector. The study questions investigated were;

1) What were the trends in farm numbers, area, and sales of US organic agricultural systems from 2008 to 2019?
2) How did land-use practices vary in US organic production systems between 2008 and 2019?
3) What were the primary challenges of US organic producers between 2008 and 2019?

2. Materials and methods

2.1. Study location and data sources

We utilized all available USDA census (national level) and survey data (state level) of certified organic agriculture production (Fig. 1, Table 1). The study was limited to USDA surveys to maximize consistency, integrity, and organic operations in the US. The data and code that support this study are available on GitHub and Zenodo(LeBauer and Guo, 2021).

2.2. Data collection

We limited the scope of this study to USDA Certified Organic Production Surveys to ensure data consistency in scope, methods of collection, and participants. State level data on farm numbers, number of hectares, and the value of sales were obtained from the USDA for the years 2008, 2011, 2014, 2015, 2016, and 2019 (USDA, 2010; USDA, 2012; USDA, 2016b; USDA, 2017; USDA, 2020), Table 1. Sales values were adjusted to July 2020 values using the U.S. Bureau of Labor Statistics 2021 Consumer Price Index Inflation Calculator (U.S. Bureau of Labor Statistics, 2021). Sales data from 2008 were also adjusted to account for the fact that the reported numbers included both certified organic and farms that were exempt from certification because they had sales less than $5000. This was corrected using guidance from NASS to assume that each exempt farm had $2500 in sales; this adjustment accounts for less than 0.3% of sales and is consistent with other USDA summary reports (USDA, 2019). One anomalous data point was removed from analysis – Alaska reported 110 ha of organic farms in 2014 and 280,000 ha in 2015, and did not report area in the two subsequent surveys; the value for 2015 was removed. In 2019, the survey question for animal and green manure were seperated compared to 2008 and 2014 where it was one question.

On-farm practices and major challenges faced by certified organic farmers were reported in the 2008, 2014, and 2018 Organic Agriculture survey data (USDA, 2010; USDA, 2016b; USDA, 2020). Most organic operations in the US participated in the census of agriculture surveys, making it an explicit representation for this study (Table 1).

2.3. Data analysis and visualization

Analysis and visualization of on-farm land use practices and major challenges faced by organic farmers at the national level were performed in R.4.1.0 (R Core Team, 2021); all code is available online (LeBauer and Guo, 2021).

Multivariate hierarchical regression model of organic farm sales, area, and number: The cleaned and transformed data of farmland area, farm number, and sales were log-transformed and modelled hierarchically in a Bayesian framework, such that state-level means were nested with the national average. We specify the likelihood for each observation i as:

$$log(Farm_i) \sim Normal(\mu_i, \Sigma)$$

where $Farm_i$ is a vector of length three (area, number, sales), μ_i is the vector of predicted values, and Σ is the 3×3 covariance matrix that describes the variability of and correlations among the three observed

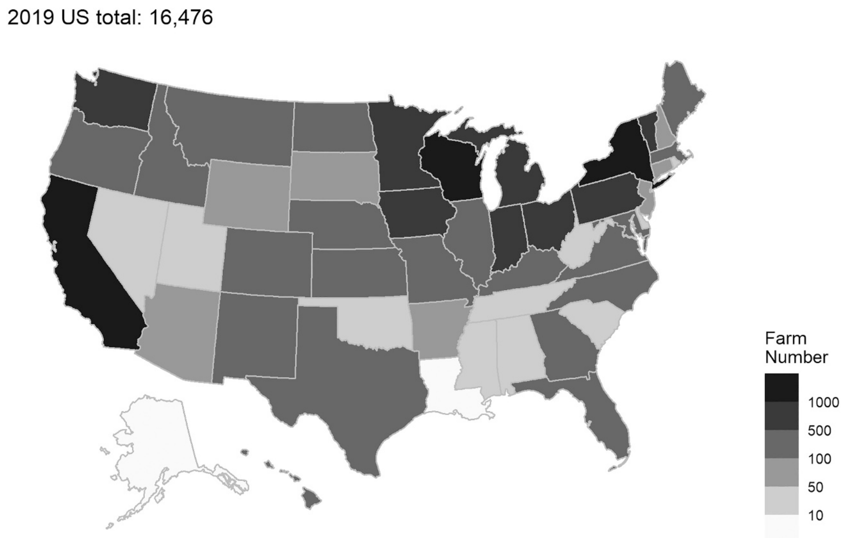

Fig. 1. Number of Certified Organic Farms in the US for 2019, by state, with only California and Wisconsin leading by more than 1000 farms. Data from (USDA, 2016b).

Table 1
Summary of available certified organic agriculture data for the US ('×' indicates data are available and included in the study) (USDA, 2010; USDA, 2012; USDA, 2016b; USDA, 2017; USDA, 2020).

Census year	Survey year	Publication year	Farms	Area	Sales	Farm practices	Challenges	Source
2007	2008	2010	×	×	×	×	×	(USDA, 2010)
NA	2011	2012	×	×	×			(USDA, 2012)
2012	2014	2016	×	×		×	×	(USDA, 2016b)
NA	2015	2016	×	×	×			(USDA, 2016b)
NA	2016	2017	×	×	×			(USDA, 2017)
2017	2019	2020	×	×	×	×	×	(USDA, 2020)

variables. Predicted values (μ) were modelled as a simple linear model, such that for each variable v:

$$\mu_v = \alpha_v + \beta_{v,s(i)} + \varepsilon_{v,s(i)}$$

where α represents the intercept, β represents the slope, and ε is the random effect of state for each variable v, and $s(i)$ denotes the states associated with observation i. We specified hierarchical priors for the state-level slopes:

$$\beta_{v,s(i)} \sim Normal\left(\mu_{\beta,v}, \sigma^2_{\beta,v}\right)$$

In order to complete the Bayesian model, a zero-centered hierarchical normal prior was specified for the state random effects:

$$\varepsilon_{v,s} \sim Normal\left(0, \sigma^2_{\varepsilon,v}\right)$$

We assigned relatively noninformative, standard priors to all remaining parameters, including the population-level means ($\mu_{\beta,v}$) and variance-related terms ($\sigma^2_{\beta,\ v}$, $\sigma^2_{\varepsilon,\ v}$, Σ).

The above equations were implemented using OpenBUGS 3.2.3 (Lunn et al., 2009) via the R package 'R2OpenBUGS' (Sturtz et al., 2005) in R (Core Team, 2021). Three independent chains were initialized with random starting values and run until convergence was achieved. Convergence was assessed with visual inspection and the Gelman-Rubin diagnostic. For each chain, a total of 3000 iterations were monitored after thinning by 20 and saving posterior calculations. The converged chains were combined and summarized as the posterior mean and central 95% credible interval (CI). The Bayesian framework also allows for simultaneous imputation of missing values, which allows us to estimate state level values of farm area and farm sales that were redacted from survey results for purposes of privacy and use these values to report national totals.

3. Results and discussion

3.1. Number of farms, hectares, and value of sales from organic agriculture in the USA

The regression model estimates at the state level exhibited high model fit (R^2 = 0.94, 0.98, and 0.96 for area, number, and sales, respectively). Thus, we confidently used imputed estimates of missing data to calculate national totals (Fig. 2). Only sales increase monotonically, while area and farm numbers declined a bit in the early 2010s (Fig. 2).

Nationally, the annual rate of change was 6%, 5%, and 12% for area, number, and sales, respectively with California leading in number of farms, farmland area, and sales (Fig 3). Montana, Wisconsin, and Wyoming followed California in farmland area. New York and Wisconsin followed in farm numbers (Fig. 1) while Washington followed in sales. The growth in organic agriculture farms, land in production, and markets in the US (Figs. 2 and 3) are driven by consumer demand for environmentally friendly production, and chemical-free food products (Rigby and Caeceres, 2000). The reduction in the number of farms and hectares in 2012 (Fig. 2) may be due to the Great Recession and/or severe drought which started in 2010, with July/summer of 2012 ranked as the second driest, only behind June – August of 1936. In September 2012, almost two-thirds (65.45%) of the contiguous US experienced severe drought (Bradley, 2015), which depressed agricultural production across the country.

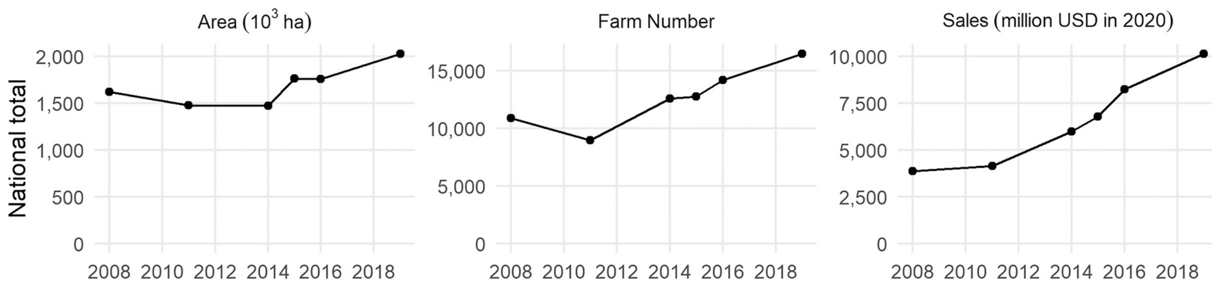

Fig. 2. National-level growth in certified organic farm area, number, and sales in the US from 2008 to 2019. Sales adjusted to 2020 values based on the Consumer Price Index. Missing state-level values of area and sales were imputed from the regression model and included in the totals.

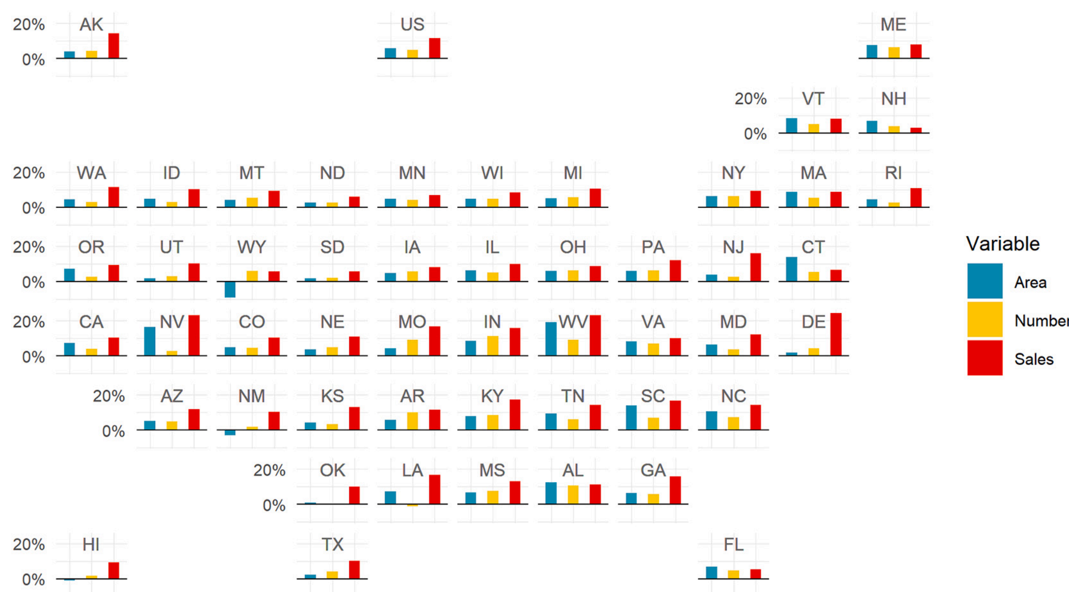

Fig. 3. Year-over-year percent growth in certified organic farm area, number, and sales by state and for the whole US from 2008 to 2019 (USDA, 2010; USDA, 2012).

3.2. On-farm organic agricultural practices in the US

Organic farmers depend on approved natural materials and biological activities and processes for on-farm management practices to meet the macro-and micro-nutritional and health needs of their organic crops (Wander et al., 2019). The most popular regenerative on-farm practices among certified organic producers in the US are green and animal manure applications (Fig. 4). While the raw number of most practices increased or stayed the same, all practices experienced proportional decline except for rotational grazing (Fig. 4). All other practices either remained unchanged or decreased with a noteable decrease in the use of organic mulch or compost (Fig. 4). General trends of on-farm practices adopted by farms from 2008 to 2019 showed increases in the total number of farms reporting the practice but declines as a proportion of the total number of organic farms.Manure and buffer strips were the most widely adopted on-farm practices, followed by the use of compost and mulch, which faced the most rapid decline in adopton of all the practices over the three year survey(Fig. 4). The survey question for animal and green manure was asked seperate in 2019, which makes it difficult to evaluate trends in these practices. In 2019 buffer strips were the most widely used practice in the organic systems (Fig. 4).

The decline in the use of green and animal manure was surprising given the association of this practice with organic agriculture. Manures supply nitrogen, phosphorus, and other nutrients required in large quantities by crops. Organic production has limited sources of NPK and other nutrients due to the prohibition of synthetic mineral fertilizers, making green and animal manures the most prominent sources for providing plant nutrients (Wander et al., 2019; Carr et al., 2020; Dubey et al., 2015; Bista and Dahal, 2018). However, there are a wide range of alternative sources of these nutrients including blood meal, fish emulsion, and even mined nitrates permitted by the USDA organic standards (Wander et al., 2019). Additionally, green and animal manures help improve soil fertility, soil health, control erosion, improve soil structure and water infiltration (Kumar and Samiksha, 2020; Kumar and Pawar, 2018), and can assist with disease management (Crow and Dunn, 2019). Challenges associated with using manure include its bulkiness, low mineral concentrations, and the slow release of nutrients, which often necessitates high application rates to meet crop nutritional requirements (Wander et al., 2019).

However, the reduction in the use of compost and organic mulches could be related to labor costs, time, equipment, and environmental issues such as smell and dust (Rynk et al., 1992; Josephson, 2018). Composting on a large scale requires special equipment, time for periodic turning, and labor. Despite the reduction in compost use in organic agriculture, it remains a major soil amendment and source of organic matter, capable of improving a soil's biological, chemical, and physical characteristics (Marriott and Zaborski, 2020). In recent years, organic mulches are being replaced by plastic and biodegradable plastic mulches leading to a reduction in the use of organic mulches (Fig. 4). Plastic and biodegradable mulches are easy to install and are more effective for controlling weeds and diseases than organic mulches which may introduce weed seeds and pathogens into the field.

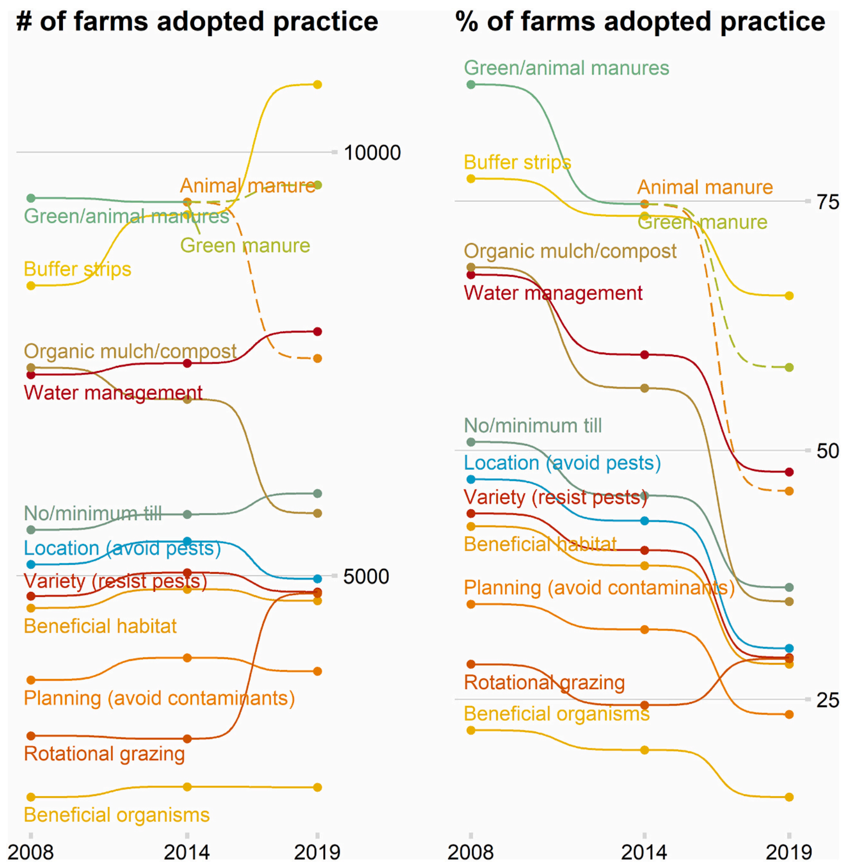

Fig. 4. Change in number and proportion of certified organic agriculture on-farm practices from USDA organic agriculture census data (USDA, 2010; USDA, 2016b; USDA, 2020). In 2008 and 2014, there was one question about use of animal or green manure; in 2019 these practices were surveyed independently.

3.3. Major challenges facing organic agriculture farmers and ranchers in the USA

The two largest challenges reported by certified organic crop producers and ranchers in the US are related to regulation and production (Fig. 5). Other problems include pricing, market access, and farm management-related issues (Fig. 5). All the reported issues among certified organic producers in the US seem to have progressively become worse from 2008 to 2019, with the percentage increase in the number of reported issues over ten years ranging from 169% (others) to 428% (pricing). Regulations, production, market access, and management-related problems are the most reported issues, increasing by 115, 190, 382, and 255%, respectively, from 2008 to 2019 (Fig. 5).

Organic agriculture is the only agricultural system defined by law with standards and regulations, making it unique from other agricultural systems (MacCormack, 1995). For this reason, regulations are an excellent way to maintain high ethical standards, boost and maintain consumer confidence, and encourage and support dedicated organic farmers and ranchers (Tate, 1994). However, regulations seem to be an obvious problem for many organic farmers, as regulatory challenges were the most frequently reported issue by farmers (Fig. 5). Reports indicate that the heavy involvement of government and international bodies in organic farming regulations could lead to resentment and a pose a threat to farmers' sovereignty which in turn dicourages adoption of organic practices. Further, globalization of agriculture with national and international certification standards would likely benefit multinational organizations and could negatively impact small-scale and family farms (Duesing, 1995).

Production issues could relate to soil fertility, weeds, diseases, and pest control, especially in the transition and early years of organic production. In most cases, organic systems produce less food per plot of land (20–25% less on average) when compared to conventional systems (Ponisio et al., 2014; Seufert et al., 2012). Organic farming prohibits the use of synthetic chemicals and fertilizers, which makes it challenging to meet the nitrogen requirements of some crops (Lassaletta et al., 2016). Fertilizer sources such as green and animal manure, commonly used in the organic systems (Fig. 4) are slow-release nutrient sources and it takes a long time to build a consistent supply of these nutrients within the soil systems (Wander et al., 2019; Carr et al., 2020; Mpanga et al., 2021a). It is possible that long-organic management could build soil health to the extent that organic system yields exceed their conventional counterparts. However, such cases are few and require several years of management and learning by organic farmers to attain yields in the organic systems that would be equivalent to or higher than the conventional systems.

The USDA has programs for organic certification cost-share and loans that are used to support organic farmers. For example, the organic certification cost-share program instituted by the USDA covering some associated costs for certified organic registration and renewal is a good starting point but is limited in scope and amount of funding. The program only supports certified farmers and not those in transition and can only support a limited number of certified farmers each year depending on funds allocated. The Farm Service Agency (FSA) also offers funding in the form of loans (Marketing Assistance Loans, Farm Facility Storage Loan, Rural Youth Loans, etc.) to organic farmers (FSA – USDA, 2020). However, research and policy reviews using a farmer-participatory approach are needed, to ensure that farmers are well-informed and to speed up innovations and technology delivery to organic producers.

3.4. Projections of United States organic agriculture

Data released from the USDA Agricultural Marketing Service in 2015

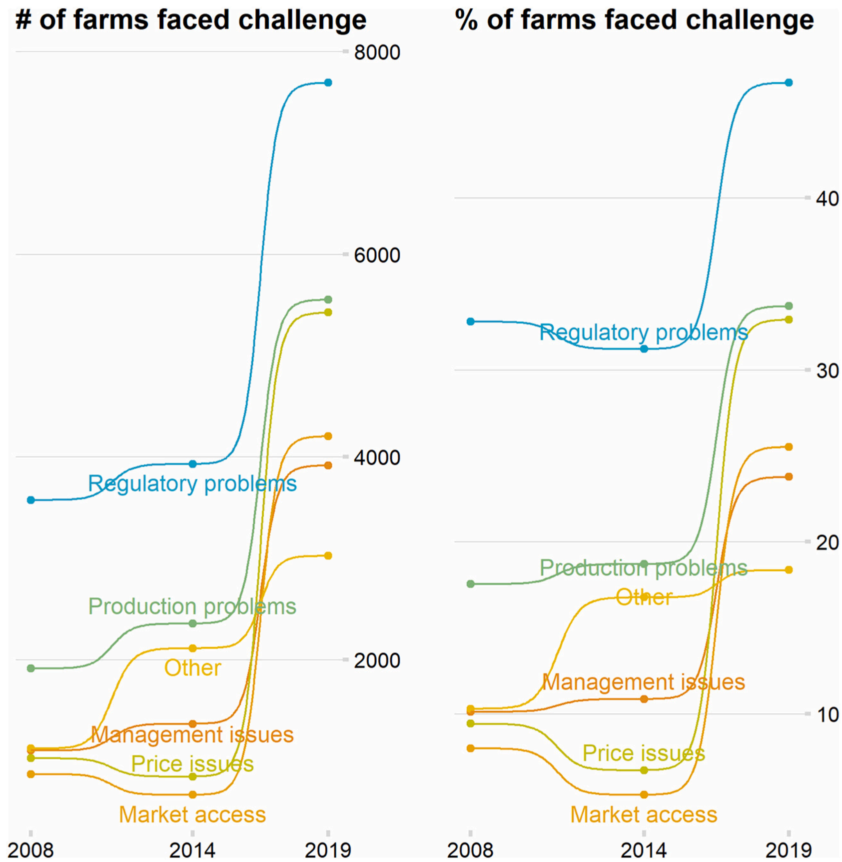

Fig. 5. Change in number and proportion of major challenges faced by certified organic agriculture farms from USDA organic agriculture census data (USDA, 2010; USDA, 2016b; USDA, 2020).

indicate that the number of farms and the sales value of US certified organic agriculture represents more than half of the world's certified organic farmers and sales value (USDA, 2016a). Based on USDA agriculture surveys data from 2008 to 2019, the number of farms, area, and value of sales of US certified organic production is increasing: annual rates of increase in organic farm numbers (5%), land area (6%), and sales (12% nominal and 165.3% inflation adjusted) at the national level (Fig. 2) are reflected across most states (Fig. 3). The increase in sales is much higher than the increase in farm numbers and farmland area, which could indicate increasing consumer demand and/or greater on-farm efficiencies, likely for larger organic farms (Fig. 3).

The certified organic market has become very established, with rapid growth in the US food market share. In 2020, Mercaris, the national leader in market data service and online trading platform for organic, non-GMO, and certified agricultural commodities confirmed that more operations and lands are being converted to certified organic farms, with increases in harvested acreage that could exceed 3.4 million acres by the 2020/21 market year (Mercaris, 2020). This is higher than projections made from the USDA census of agriculture data (Fig. 2). To continue with the progress made in organic agriculture systems, issues reported by certified organic farmers as shown by their increasing trends (Fig. 5) must be addressed to enhance and expand certified organic production systems in the US.

(Ikerd, 1993) reported that most organic operations are sustainable when compared to conventional systems and that they could maintain productivity and usefulness to society over a long period, with key indicators such as resource conservation, economic profitability, social acceptance, commercial competitiveness, and environmental benefits. The organic system cannot be labelled as sustainable all the time because some fundamentally vital indicators may not be met. In some instances, the economic profitability indicator becomes more challenging to meet during the early years of transition. Also, large organic farms producing at one location and transporting products across the nation, may be increasing the carbon footprint on the environment and may be less sustainable except in some special cases. For example, producing lettuce in an area with a unique climate of mild winters such as Yuma, Arizona and shipped across the US where they cannot grow outside during the winter is still likely cheaper and more sustainable than current indoor production in those cold areas where they must utilize great amounts of energy for indoor climate controlled heating. To reduce long-distance transportation of organic produce and the associated greenhouse gas emissions, small-scale farmers could play a vital role by supplying organic produce within their localities, thus reducing transportation across counties, states, and countries (Mpanga et al., 2021b). Also, the ongoing carbon market could be a boost to the organic farming sector, providing more profitability from the regenerative practices through carbon credits. Nevertheless, regulations should be simplified to allow small- and medium-scale farmers to convert into organic agriculture and not be so complicated that only large farms can justify obtaining the knowledge and expertise to produce as certified organic with all the regulations.

4. Conclusion

US's organic farming has attained a significant milestone by increasing farm numbers, farmland area, and organic sales, with a great potential to supply synthetically chemical-free food products using regenerative, sustainable, and environmentally-friendly agricultural practices. However, to sustain the growth trends of organic production in the US, which are driven by consumers and the need to reduce the negative impacts of farming on the environment, the challenges faced by organic producers need to be addressed. Also, farmer-participatory research on local production and policy reviews of existing regulations and practices that will promote small and family farms in the organic market are required. Finally, site-specific research and extension on land management strategies are needed for soil nutrient management, economic viability, and environmental conservation using a farmer-participatory approach.

Declaration of Competing Interest

The authors do not have a conflict of interest related to this work.

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