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Sustainable Agriculture Practices as a Driver for Increased Harvested Cropland among Large-Scale Growers in Arizona: A Paradox for Small-Scale Growers

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Extreme climate variability is a major factor threatening crop production in Arizona State. However, limited information exists on how growers are adapting with land-use practices. Using data from the National Oceanic and Atmospheric Administration and the Agricultural Census (2012 and 2017) of the US Department of Agriculture, this study investigates trends of land-use practices among small- and large-scale growers and their possible effects on harvested cropland. From 2012 to 2017, there are reductions in total farmlands (–0.5%) and vegetable production lands (–4%) with varying temperatures, precipitation, and drought severity index. However, harvested crop- and vegetable land increased by 3% and 11%, respectively, which was mainly influenced by large-scale growers. This coincided with an increase in sustainable land-use practices such as conservation agriculture no-till (103%), reduced tillage (71%), and cover cropping (123%) which are most popular among large-scale growers. Manure application also increased by 30%. However, there were reductions in other practices such as intensive tillage (–9%), use of commercial fertilizers (–0.2%), nematicides (–63%), and chemical diseases control (–16%). Unfortunately, non-sustainable practices (irrigation, insecticide, and herbicide application increased by 27%, 39%, and 10%, respectively. This study reveals potential benefits of sustainable agricultural practices in Arizona and a need for increased adoption among small-acreage growers.

1. Introduction

Arizona is located in the southwest of the United States of America with agriculture playing a pivotal role in the state economy and is ranked third in supplying food for the country. However, the state is diverse in terms of climate conditions, farm operations, and grower demographics. The state is 335 miles east to west and 390 miles north to south with varied climate zones (Colorado Plateau in the north with 5000–8000 feet, Transition or Highlands zone in the middle, and Basins and Range in the south with the lowest elevation). The evapotranspiration-loss of water from soil and plants in a location is mostly greater than the amount of rainfall the area receives.[1] Most growers in the state, therefore, depend on irrigation for their operation with up to 74% of the state's water used in agriculture.[2] This requires sustainable on-farm land-use practices such as conservation agriculture (CA) which has demonstrated yield benefits in dry areas.[3] According to the Food and Agricultural Organization (FAO), CA is described as a system with permanent or semi-permanent organic soil cover (growing crop or dead mulch) under minimal to no mechanical disturbance of the soil. The main function is to protect the soil from sun, rain, and wind and to serve as a carbon source for soil microorganisms.[4]

The use of CA practices is reported to have many benefits including soil health and fertility, erosion control, water infiltration and use efficiency, soil structure improvement, carbon sequestration, weed control, etc.[5] Though the CA practice is widely promoted and adopted in America, the adoption rate varies among growers based on scale of operation (small- and large-scale growers) especially in areas like Arizona with varied demographics of farmers.

Demographics of growers in Arizona are interesting based on acreage, operator gender and race, operation size, and household income. About 60% of the growers are small-scale farmers with 0–200 acres of farmland. More than 87% of the farmers earn less than $ 25 000 per year as their household income with native Americans and women constituting about 50% of farmers in the state (United State Department of Agriculture,

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USDA, 2012 Census of agriculture; Bickel et al 2017).[6] Most of these farmers can be categorized as historically underserved farmers and ranchers based on the Agriculture Improvement Act (2018 Farm bill) because they are socially disadvantaged, beginning farmers, limited resource farmers, or veteran farmers.[7] Most of these demographic factors especially operation size (small- or large-scale) and income could affect sustainable land-use practices such as CA. Unfortunately, not much comprehensive research information is available on the trends of sustainable on-farm practices such as CA among small- and large-scale growers and their possible effects on harvested cropland in the state.

This research reviewed USDA agriculture census data for 2012 and 2017 to assess sustainable agricultural practices and their possible impact on harvested cropland among small- and large-scale growers in Arizona.

2. Experimental Section

2.1. Climate Data

Climate data (temperature, precipitation and drought severity) were obtained from National Oceanic and Atmospheric Administration (NOAA), National Centre for Environmental Information (NCEI) (NOAA, 2019) to get an overview of the climate conditions in the state of Arizona and its possible contributing effects on harvested croplands within the study period.[8]

2.1.1. Temperature

To calculate the respective projected maximum temperature for the period 2018–2023, projected factors obtained from online monthly graphs at NOAA and NCEI were added to all 2012–2017 monthly averages.

2.1.2. Drought

The Palmer Drought Severity Index (PDSI) data obtained from the NOAA and NCEI websites were used to quantify moisture conditions during the study period in the state. The PDSI is a standardized index that ranges from −10 (dry) to +10 (wet). It is used to measure dryness based on recent precipitation and temperature.[8]

2.2. On-Farm Practices Data

2.2.1. Data Collection

All data were collected from the USDA and National Agriculture Statistical Service website on the 2012 and 2017 agricultural census.[6a] The following variables were included in this study:

1) Total land in farms and in vegetable operations
2) Harvested cropland for all crops and for vegetables, potatoes, and melons
3) Acreage under conservation practices (no-till, reduced tillage, cover cropping)
4) Other on-farm agricultural operations such as
   a) Intensive tillage practices
   b) Mineral fertilizer applications with the term commercial fertilizer (this includes lime and soil conditioners)
   c) Irrigation
   d) Herbicides, insecticides, nematicides, and other chemicals for disease control
   e) Manure applications

2.2.2. Calculations

To study trends of the measured factors, percentage differences between the two census years were calculated based on the formula below

$$\%\Delta = \frac{Y_2 - Y_1}{Y_1} \times 100 \tag{1}$$

where $\%\Delta$ = percentage change, Y_1 = 2012 data, and Y_2 = 2017 data.

2.2.3. Data Limitation

Some data points were withheld for privacy reasons or missing, which made it impossible to calculate the percentage changes for all parameters. Data on irrigation, fertilizers and chemicals used in controlling weeds, pests and diseases based on farm size were not presented in the census data. However, this did not affect the objective of the study.

3. Results

3.1. Climatic Conditions

3.1.1. Precipitation and the Palmer Drought Severity Index

In Arizona, the average yearly precipitation in 2012 and 2017 was the same at per month. However, precipitation was higher from 2013 to 2016 with the highest yearly average of per month in 2015 (**Figure 1**A). Interestingly, PDSI was reduced by 50% from 2012 to 2017 with the lowest severity in 2015, coinciding with the highest precipitation. Generally, PDSI in Arizona is very high with average values of −2.31 from 2012 to 2017 (Figure 1A), which could affect land used for farming and crop harvest.

3.1.2. Temperature

Temperature is one of the most important factors affecting crop production and has a range within which species can thrive. According to the data from NOAA, the average yearly maximum temperature in Arizona increased from 75.2 °F in 2012 to 75.9 °F in 2017 and is expected to reach 77 °F in 2018 and 77.7 °F in 2023, showing an increasing linear trend (Figure 1B).

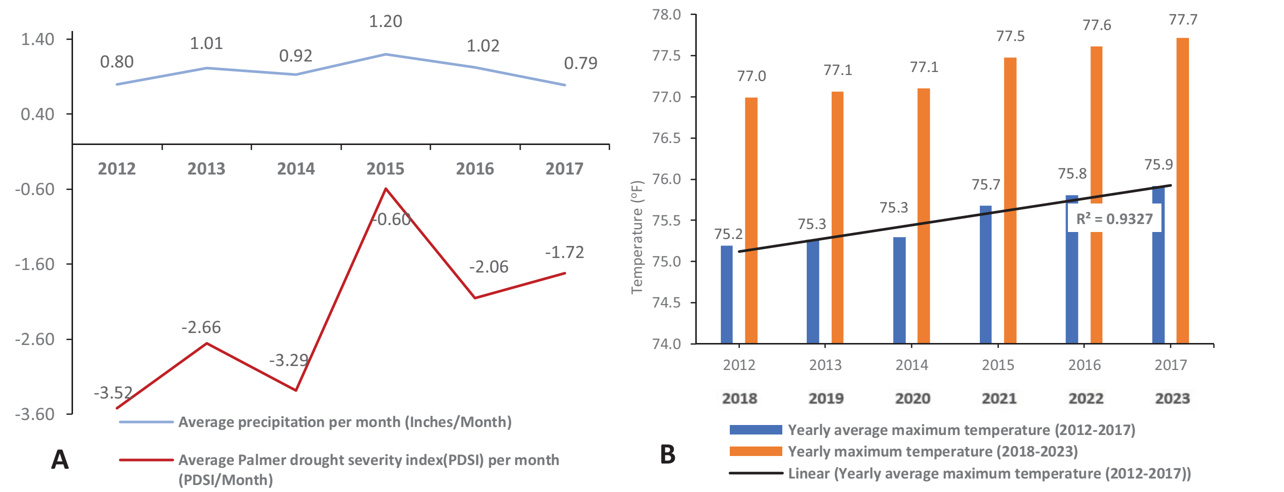

Figure 1. A) Yearly average per month and drought severity index and B) maximum temperatures from 2012 to 2017 and projected from 2018 to 2023 (calculated based on the projected figures from NOAA) in Arizona state. Data obtained from the National Oceanic and Atmospheric Administration (NOAA), National Centre for Environmental information:[9] The linear regression and R^2 were calculated from the 2012 to 2017 data.

3.2. Total Land in Farm Use and Harvested Cropland

In Arizona, the acreage of total harvested cropland and land in vegetable production increased by 3% and 11%, respectively, from 2012 to 2017. However, the total land in farms and vegetable production decreased by 0.5% and 4%, respectively (**Figure 2**). The market value of the 11% increase in harvested vegetables land was estimated to be 35% in the same period.[6a]

3.3. Harvested Cropland Based on Farm Acreage

The 3% increase in total harvested cropland and 11% increase in vegetables harvested (Figure 2) in the state was influenced by the extremely large-scale growers (**Table 1**A,B). However, the results were contrasting among small-scale farms with a strong decrease in harvested crop and vegetable lands (Table 1A,B).

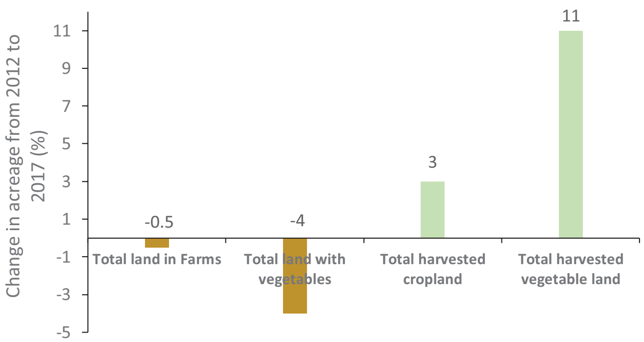

Figure 2. Changes in land use in farms, land in vegetables, total harvested cropland, and total harvested vegetable land in Arizona between 2012 and 2017 USDA census years.

Table 1. Percentage changes in A) total cropland based on acres harvested and B) harvested vegetable land based on farm sizes between 2012 and 2017 in Arizona based on farm size. Data adapted from USDA 2017 agriculture census.[8a]

	2012	2017	% Change
A. Total harvested cropland [acres]			
1–9	10 200	7494	−26.5
10–19	7599	5132	−32.5
20–29	4386	2941	−32.9
30–49	5986	6259	4.6
50–99	13 771	11 591	−15.8
100–199	25 890	21 362	−17.5
200–499	81 324	61 504	−24.4
500–1000	108 295	114 009	5.3
1000 and more	632 679	685 335	8.3
B. Harvested vegetable land [acres]			
0.1–0.9	295	221	−33.5
1–4.9	1840	1054	−74.6
5–14.9	1196	330	−262.4
15–24.9	267	95	−181.1
25–49.9	714	591	−20.8
50–99.9	812	493	−64.7
100–249.9	2562	2712	5.5
250–499.9	1800	3498	48.5
500–749.9	2956	2939	−0.6
750–999.9	4296	7815	45.0
1000–1999.9	20 441	14 368	−42.3
2000–2999.9	12 420	20 989	40.8
3000–4999.9	25 231	32 205	21.7
5000 and more	55 515	57 691	3.8

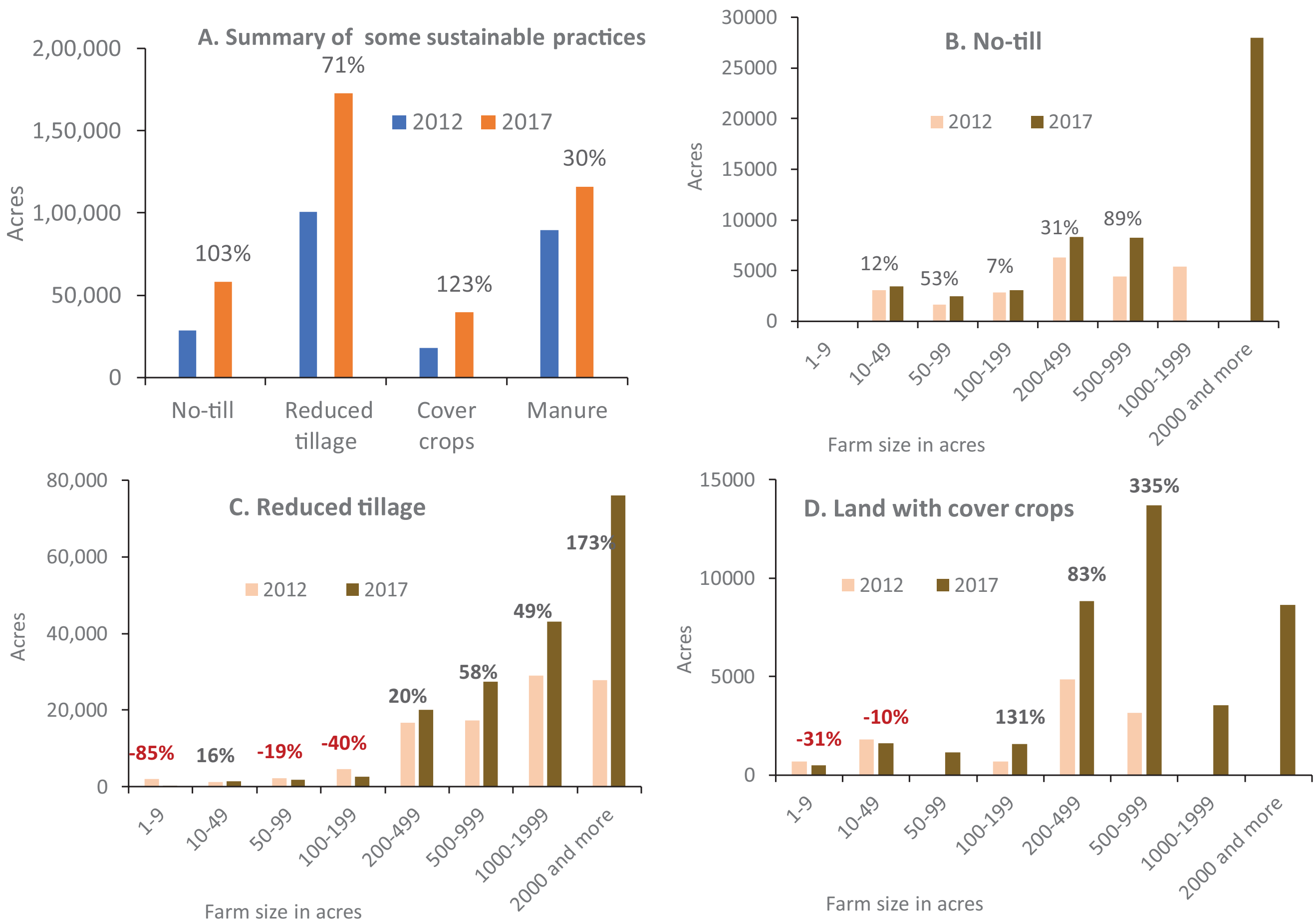

Figure 3. A) Summary of sustainable agriculture practices, B) No-till, C) reduced tillage (excluding no-till), and D) cover cropping (excluding crop rotation) practices in Arizona. Data adapted from USDA 2017 agriculture census. Values above the bars represent the percentage change between 2012 and 2017 USDA agricultural census years.[6a]

3.4. Sustainable On-Farm Practices

Some sustainable on-farm practices considered in this study were conservation agriculture practices and the use of manure.

3.4.1. Conservation Agriculture

No-Till: The no-till practices seem popular in Arizona with a 103% increase between 2012 and 2017 (**Figure 3**A) with significant dominance among large-acreage growers with 200 acres or more (Figure 3B). This trend could be related to soil health and environmental benefits, reduced cost for fuel and government incentives for no-till practices.[9]

Reduced Tillage: The trend for reduced tillage practice in Arizona increased by 71% (Figure 3A), which was significantly practised among the large-scale growers with 200 acres and more up to over 100% increase in farms with 2000 or more acres. However, the practice was unpopular among small-scale growers within the same study period (Figure 3C).

Cover Cropping: The use of cover crops increased by 123% in Arizona in the same period (Figure 3A). Once again, the significant increase could have been triggered by large-scale growers with more than 200 acreages (up to 100% increases in farms with 200–499 acres and more than 200% in farms with 500–999 acres). In the same study period, the use of cover crops remained unpopular among small-scale growers with even a reduction among farms with 1–49 acres (Figure 3D).

3.4.2. Manure Application

The use of manure in the state increased by 30% from 2012 to 2017 among all growers without data based on farm size (Figure 3A).

3.5. Other On-Farm Practices

This includes all other cultural practices such as intensive tillage, irrigation, commercial fertilizer applications, and the use of chemicals to control pest, diseases, and weeds, which are not considered under Section 3.4. In this group, there was no available data based on farm size.

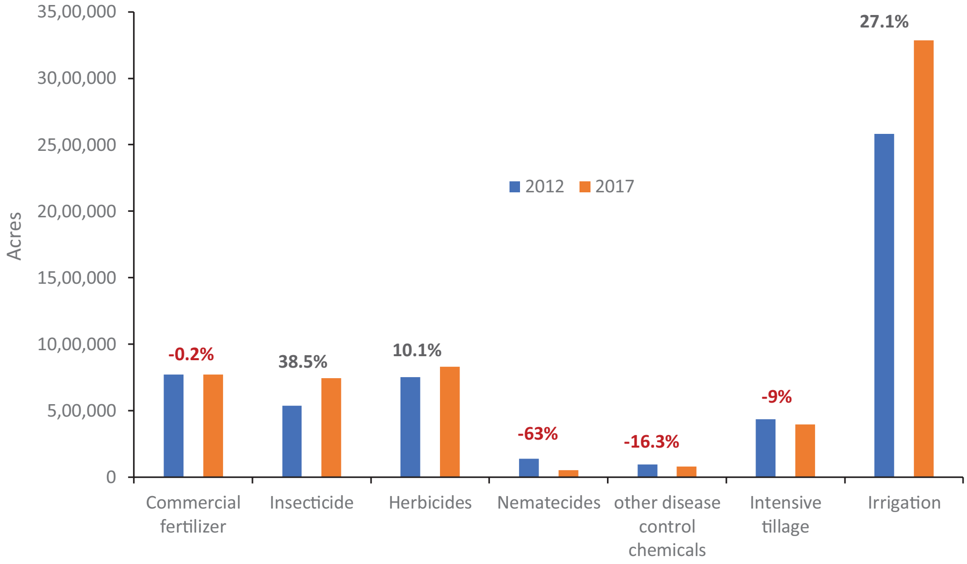

Figure 4. Percentage changes of fertilizer and chemical applications in Arizona between 2012 and 2017. Commercial fertilizers (including lime and soil conditioners); insecticides include chemicals for insects and other pest control; herbicides include chemicals for weeds, grass, and shrub control; other chemicals used include those for disease control on crops and orchards. Data obtained from 2017 USDA agricultural census.[6a]

3.5.1. Intensive Tillage

Irrespective of the farm size and county, intensive tillage practices were reduced by 9% (**Figure 4**), which was expected due to the increases in reduced and no-till practices in the state (Figure 3A).[6a]

3.5.2. Commercial Fertilizer Application

The use of commercial fertilizers which included lime and soil conditioners was slightly reduced by 0.2% from 2012 to 2017 (Figure 4). However, in counties such as Coconino and Yavapai with mostly small-scale growers, the use of commercial fertilizers increased by 123% and 18%, respectively, with a drastic drop in total harvested cropland.[6a]

3.5.3. Nematodes and Disease Control

The land under application of chemicals to purposefully control nematodes and diseases was significantly reduced by 63% and 16%, respectively (Figure 4). The use of CA practices is known to improve soil health with a strong pool of soil microbial community from where the plant recruits the beneficial one to their advantage to suppress diseases and pathogens.

3.5.4. Irrigated Cropland

In the state of Arizona, irrigation is an essential component of agricultural production with about 74% water used in agriculture.[2] This is clear in the data presented in this study with a 27% increase in irrigated cropland (Figure 4).[6a] Irrigation application methods such as buried drip, surface drips, and center pivot has been reported to increase crop yield.[10] However, factors such as soil strength and compaction can limit the effectiveness of irrigation on crop yield especially in no-till systems.[11]

3.5.5. Insecticides and Herbicides

The acreage on which chemicals were applied to control insects increased by 39% while the control of weeds, grasses, and shrubs increased by 10% in the state (Figure 4).

4. Discussion

This study identified interesting trends with reduced total farmlands but increased harvested cropland in Arizona between 2012 and 2017 based on the agricultural census. The increase in harvested cropland was mostly due to large-scale growers among whom sustainable practices such as no-till, reduced tillage, and cover cropping were widespread. Other farm practices such as the use of manure, insecticides and herbicides, commercial fertilizers, intensive tillage practices, chemicals for the control of diseases and nematodes, and climate factors (precipitation, drought severity index, and temperature) are discussed in the context of sustainability practice. In the following subsections, we will discuss possible contributing factors that influenced the increased in harvested cropland in the midst of climate variability (Figure 1).

4.1. Farm Operation Size

Change in harvested cropland between the 2012 and 2017 USDA agriculture census years varied greatly. While extremely large growers with 500 acres or more made gains, small-scale growers lost up to 30% of harvested cropland. Reasons could be that large-scale growers have access to credit, equipment, experience, and land for CA and irrigation practices (Figures 3B–D and 4), which could compensate the effects of low precipitation, drought severity, and increasing temperatures (Figure 1A,B), hence the increases in harvested cropland especially harvested vegetable land among them (Table 1A,B). The increase in harvest is a great incentive for these farmers.

Small-scale growers on the other hand may have less accessibility to credit, and the cost to implement conservation agricultural practices that require special equipment may act as a disincentive, hence the low popularity of CA practices and negative effects on harvested cropland among them (Table 1). To promote the use of sustainable practices such as CA among small-scale farmers, research into locally adapted and cheaper innovative tools and strategies must be explored further.

4.2. Sustainable Farm Practices

Sustainable farm practices discussed here include CA practices and manure application and their related benefits and challenges.

4.2.1. Conservation Agricultural Practices

Conservation practices including no-till, reduced tillage, and the use of cover cropping have been reported to have many benefits such as soil erosion control, improved soil health and soil fertility, weed control and improved soil carbon sequestration.[5] Also, CA is known to be a climate-smart agricultural practice with less impact on greenhouse gas emissions, improved soil water quality, and reduction of pollutants such as nitrate in water bodies.[12] Therefore, the massive increases in the use of CA practices in Arizona, especially among large-scale growers (Figure 3), could be a direct driver for the increases in harvested cropland and vegetables lands (Table 1), despite rising temperatures, less precipitation, and high drought severity index (Figure 1). Under these climate conditions with drought severity, increase in irrigation practices could also be a strong contributing factor for the increase in harvested acreage.[10] While a meta-study by Ogle et al. reported no changes in productivity with no-till in wet and/or cool areas,[13] long-term studies revealed that CA was beneficial only in dry years and areas.[3,14] Accordingly, to increase harvested cropland in semi-arid conditions such as Arizona (Figure 2 and Table 1), sustainable on-farm CA practices such as no-till, reduced tillage, and cover cropping (Figure 3) are required. The general shift from intensive tillage to CA practices would lead to soil health improvements that could reduce the incidence of diseases and nematodes in fields.[15] Reduction in chemicals applied to control diseases (−16%) and nematodes (−63%) in the state may be attributable to the widespread use of CA practices (Figure 4), is more associated to drought stress, which is known to reduce soilborn diseases (fungi and nematodes).[15,16] Additionally, the use of CA practices could affect other cultural practices such as irrigation, commercial fertilizer application, and the use of chemicals for pest and disease control.

4.2.2. Manure Application

Unlike commercial fertilizers, manure application increased by 30% in the state (Figures 3A and 4). This practice has associated benefits such as improved soil structure and texture, soil water infiltration and water holding capacity, and even soil health. Just as we cannot rule out the contribution of manure to the gains made in harvested croplands, data were limited in terms of farm size, which made it difficult to directly relate the benefits to the increases in harvested cropland. Manure is a common and cheap soil amendment material in Arizona due to livestock production such as cattle, sheep, and poultry.[6] In the context of CA, especially no-till, manure application methods must be carefully selected and managed to maximize nutrient use, avoid environmental problems such as water pollution, volatilization, and emission of greenhouse gases and at the same time adhere to the CA principles such as soil cover. To meet this goal and be sustainable in the use of manure, injection and strip applications are recommended by Al-Kaisi et al.[17] but may be too expensive especially for small scale farmers. Small scale farmers could compost the manure and also use chisel or aerator equipment in reduced tillage systems to help incorporate the manure. However, more research on innovative and cheaper manure application methods is required for small scale farmers using locally available or adapted tools and equipment.

The use of manure could also be a source of zoonotic (*Escherichia coli* and *Salmonella*) disease contaminations in crop fields which can be transferred to humans and bacteria resistance to antibiotics due to excessive use in animal production. Composting could be a way to partially overcome this challenge,[18] which will not work in the case of bacteria resistance. To sustainably use manure in crop productions therefore calls for more careful approaches which should involve animal producers. When possible, antibiotic use in animal husbandry should be moderated including the use of alternative practices and preventive measures such as the use of disease resistant breeds and good hygiene practice protocols at all stages.

4.2.3. Challenges of Small-Scale Growers in the Use of Sustainable On-Farm Practices

Despite the enormous benefits of sustainable practices such as CA, its practical application among the small-scale growers is limited due to scarce research information, financial constraints, machinery, land, experience, and technical expertise. Stevenson et al. stated that economic disincentive, yield, and environmental factors affected the adoption of CA in Sub-Saharan Africa and South-Asia, which may have parallels in Arizona.[19] Subsidy programs with focus on small-scale farmers, especially during transition years from conventional to CA, could be an effective incentive as well as additional structured educational programs on the long term benefits of CA.

4.3. Other On-Farm Practices

In the state of Arizona, irrigation is an important component of agricultural production with about 74% used in agriculture and horticulture.[2] The 27% increase in irrigated croplands in the state (Figure 4) was expected since most of the year is dry with low precipitation and high drought severity index (Figure 1). Greater adoption of CA practices could increase water use efficiency through the reduction of evaporation from the soil surface and improve water infiltration and storage, which could contribute to crop yield.[20] Also, acreages on which chemicals were applied to control insect and weeds increased by 39% and 10% (Figure 4), respectively. However, no categorical data were available on farm size to decipher their contribution to harvested cropland.

The use of CA practices such as no-till and reduced tillage is associated with increases in herbicides and pesticide used especially in the early years of transition from intensive tillage. However, in this study, the increase in use of herbicides was only marginal (10%) (Figure 4) despite a large increase (70–100%) in CA practices (Figure 3). Farmers seem to manage weed control in their CA systems more efficiently by planting more cover crops (Figure 3). Alternative management for the weed control could be targeted irrigation, fertilization practices, and adapted crop rotations.

In no-till systems, the plant debris could serve as habitat for pests, especially in temperate agriculture with humid conditions,[15] which could be the reason for increase in pesticides application (Figure 4). Relying solely on the use of chemicals for pest control is not a sustainable approach but could be managed sustainably through synergistic use of different CA methods such as variety selection, adjusting planting date and row spacing, fertilizer application date and methods, crop rotation, cover crops and the use of biocontrol methods.[21] Systematic and consistent prudent practices of CA could improve soil health by fostering an abundance of beneficial soil microbes that would suppress pests and diseases and support healthy plant growth.[5a]

Other complimentary strategies and approaches could be used to support CA practices. In a global meta-analysis study, the use of biofertilizers was reported to be more beneficial to improving crop yield, and P and N use efficiency in dry areas (Schütz et al.[22]). Also, biofertilizers improved P recovery from organic fertilizers, both in field crops such as maize and vegetables, such as in tomato (Li et al.,[23d] Mpanga et al.,[23a] Vinci et al.,[23b,c] and Bradacova et al.[23e]). These practices maybe adopted and integrated into CA systems in Arizona for crops production with efficient irrigation and fertilization strategies.

5. Conclusion and Outlook

Under extreme climate conditions such as the predicted rise in temperatures, reduction in precipitation, and high drought severity index coupled with the competition of farm land for other purposes as in Arizona, efficient use of irrigation and CA practices seem to be management options to sustainably produce crops. Unfortunately, the CA practice is only popular among large-scale growers with a seeming disincentive among small-scale growers. This calls for more aggressive policies, incentives, and nonformal educational programs that will promote CA as sustainable practice among small-scale growers. The rise in the use of irrigation and pesticides require sustainable management measures. To harness CA potentials in Arizona, Extension programming and research efforts should focus on locally adaptable strategies and tools that will target improvement in soil health, nutrient, and water use efficiency for sustainable crop production and resilience to variable climate and climate extremes.

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Conflict of Interest

The authors declare no conflict of interest.

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