Organic Transition: Unwrapping Challenges for Growing Vegetables

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 6, 2023

Keywords: growing systems, cultivar selection, land use,
growing degree days, soil physical properties, crop yield

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Abstract

This study was conducted using four different growing systems (high tunnel, conventional open field, organic open field, and hydroponics) to determine which growing system would have the greatest results for lettuce production in the Southeastern U.S. Also, within this study, research for transitioning from conventional to organic vegetable production was reported. Land use treatments included fallow ground, tillage, cover crop, and the growing of a vegetable crop (i.e., tomato). Results indicated that lettuce cultivars Truchas, Monte Carlo, and Breen are well suited to organic systems, Bluerock, Breen, Coastal Star, Milagro, Newham, and Panisse are well suited to high tunnel system, and Grazion, Panisse, Salanova Green Butter, and Bauer are well suited to hydroponics systems. In the transition to organic production, planting sorghum as a cover crop was the most advantageous method to reduce weed pressure, reduce soil compaction, and promote beneficial soil parameters.

Acknowledgments

I would like to thank Dr. Andre da Silva for his guidance and support during this master's research. I would also like to express my gratitude to Dr. Wheeler Foshee, Dr. Camila Rodrigues, and Dr. Emmanuel Torres for their contributions and professional expertise during this research project as committee members. I would also like to thank the Vegetable Crops Team at Auburn University for their assistance with field operations, data collection, and lab work. Lastly, I would like to thank my wife, Callie Dorminey, for all the assistance provided throughout this research.

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List of Abbreviations

CONV   Conventional growing system

ORG   Organic growing system

HT   High tunnel growing system

HYDRO   Hydroponic growing system

GDD   Growing degree days

NFT   Nutrient film technique

SPAD   Leaf chlorophyll concentrations

Bd   Soil bulk density

PWP   Permanent wilting point

FC   Field capacity

SAT   Saturation

AW   Available water

DAT   Days after transplant

Chapter 1

Literature Review

Vegetable Growing Systems
High Tunnel Systems

High tunnels are temporary structures covered with greenhouse-grade plastic used to change the growing environment (O'Connell et al., 2012; Reeve and Drost, 2012). Although the United States started using this method later than many other countries, the popularity of high tunnel production has been quickly gaining traction (Lamont, 2009). This increase in popularity is due in part to the increasing demand for locally grown and organically grown vegetables and produce throughout the United States (Conner et al., 2009). The low cost of high tunnel structure materials and construction makes high tunnel production an appealing alternative to field production on both the commercial and private scale. In addition to the low costs, high tunnel growing systems provide other benefits such as the ability to extend the growing season, reduction of crop risk due to weather, disease, or pests, and the large-scale production that can be achieved on a relatively small area of land (Blomgren and Frisch, 2007; Lamont, 2009).

High tunnels are temporary structures used to extend the growing season and offer some degree of control over the environment and increased protection from extreme weather events and pests (Lamont, 2009; O'Connell et al., 2012; Reeve and Drost 2012). Despite appearing remarkably similar, high tunnels and greenhouses are vastly different technologies. High tunnels are temporary, have a simple pipe or similar frame with a single layer of greenhouse grade plastic over the structure, and no automatic ventilation or heating system although they often have a system of irrigation for watering; plastic greenhouses, on the other hand, have a double layer of inflated plastic, fully automated ventilation and heating systems, and offer much more

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control over the environment than do high tunnel systems (Lamont, 2009; Lamont et al., 2002; Wells, 1998).

High value crops such as lettuce are often grown under high tunnels, especially to add protection to allow for season extension (Wallace et al., 2012). In warmer regions, such as the southeastern United States, lettuce production is limited during spring and summer months due to high temperatures that can lead to crop damage (Simonne et al., 2002). Similarly, planting lettuce under high tunnel during winter and early spring can mitigate risks and damages associated with planting lettuce early in the open field during cooler temperatures and increase lettuce quality and yield (Zhao and Carey, 2005).

Previous studies compared the yield and quality of several lettuce cultivars grown under high tunnel and open field conditions in three different climate regions in the United States. Results showed that climate plays a significant role in determining the benefits of planting under high tunnel (Wallace et al., 2012). Some cultivars produced higher quality and yield under high tunnel than they did in the open field, and other cultivars were of higher quality and yield in the open field than under high tunnel. Generally, high tunnel production of lettuce can be beneficial in the southern regions of the United States by allowing for earlier lettuce production when there is risk from freezing, wind damage, or both (Wallace et al., 2012).

Hydroponics. A method of growing plants without soil and instead using either a nutrient solution or supporting plants with an inert medium; either method has the same result: plants receive their nutritional needs solely through irrigation water (Kaiser and Ernst, 2016). While there are numerous hydroponic systems that can be used with great success, they all have the same drawback of being demanding in that hydroponics requires a greater amount of knowledge, skill, financial investment, and experience than most other greenhouse operations (Kaiser and

Ernst, 2016). Additionally, the market for hydroponic lettuce is much smaller than for other methods of farming, and a target market willing to pay premium prices must be found in order to offset the costs of growing using a hydroponic method (Kaiser and Ernst, 2016).

Although hydroponics offers many benefits such as the opportunity to provide a covered and climate-controlled environment as well as optimal nutrition for crops and prolonged shelf life after harvest, there are also many challenges associated with hydroponic systems (Kaiser and Ernst, 2016). One challenge lies with simply selecting the crops that should be planted in the system. Lettuce is an excellent crop to produce using hydroponics, and some cultivars have been specifically produced for use in various hydroponic systems. The most common types of lettuce grown in hydroponics are butter, romaine, and looseleaf due to their market demand, disease resistance, superior growing capabilities within a greenhouse hydroponic system, and degree of coloration (Kaiser and Ernst, 2016). Crops that do not provide these benefits may not do well growing in the system or returning profit due to low market demand. Another challenge of hydroponics is the proclivity to water-borne diseases and pathogens that can easily affect the entire recirculating system (Kaiser and Ernst, 2016). When water is introduced to the system, special care must be taken to ensure the water is free of contamination and disease. Additionally, water often attracts insects that could damage the crop. Ensuring that the system remains free of insects can pose a problem as even the smallest opening around external equipment access can grant them the opportunity to become a threat to the crop. Despite all the challenges associated with hydroponic systems, their excellence in producing profitable and sustainable crops cannot be overstated.

Conventional farming. This technique has been the norm for centuries. Technology has increased productivity, quality, and yield of crops farmed conventionally, but the basic techniques of this type of farming have remained the same. Nutrients are added to the soil via fertilizers and chemical compounds to increase growth, appearance, and marketability, and other chemicals can be sprayed on the plants at various stages of growth to keep pests away and prevent diseases from decimating the crop. Although this farming method has been able to continue making improvements and increasing yield, the push away from conventional farming towards the adoption of other farming methods has added niches in the market. Even so, conventional farming methods are still the frontrunner when it comes to lettuce production in the United States; however, by the year 2030, it is predicted that organic and conventional yields will be nearly equal (Crusha, 2011).

Organic Farming. Having gained popularity in recent years, the benefits of such farming techniques have been thoroughly studied and documented. In addition to mitigating many of the environmental impacts seen with conventional farming, organic farming offers the grower the added benefits of reducing the long-term cost of production and ensuring price premiums for organically grown produce while granting the consumer a healthy and safe product (Nedumaran, 2022; Baker et al., 2022).

Although organic farming offers many benefits, it can be difficult to make the transition to organically grown crops. The first several years of transition to organic production are typically less profitable for the farmer as there is typically a reduction in yield and crop quality that comes with not adding nutrients back into the soil as is done in conventional farming. While not all crops are selected for success using organic farming methods, lettuce has shown great promise in its ability to transition well to organic production. Bringing in nearly $1.5 billion in

2013, lettuce is one of the most popular cool season crops in the United States (AgMRC, 2015). As lettuce is such an important crop, its inclusion in organic production methods was inevitable. In the United States, farmland reserved for organic lettuce production increased from 4% to 12% between 2005 and 2011 bringing lettuce in as the number one organic crop (ERS, 2013; USDA,2015). Most of the organic lettuce currently produced in the U.S. is in Arizona and California (Toland and Lucier, 2011). As organic lettuce production continues to improve, the number of organic farms producing lettuce in the United States should also continue to increase. In addition to granting growers increased profitability, this increase in organically farmed lettuce will also begin to remedy the negative effects conventional farming methods have on the environment (Jouzi et al., 2017). With increased profitability and improved environmental conditions on their farms, growers will be able to further expand their operations and improve their farming techniques which will in turn benefit the market.

Challenges with Organics

Although the benefits of organic farming are numerous, there are many challenges associated with transitioning to an organic operation that keep many farmers hesitant to make the conversion. Challenges encountered in organic farming include nutrient and pest management, education and certification, reduced crop yield, and increased investment of time and money with little to no return (Jouzi et al., 2017). Though the challenges seen in organic production are most abundant during the first three to five transitional years, the prospect of facing these challenges immediately after the decision to convert to organic dissuades many farmers from making the effort to begin growing organically (Lotter, 2015).

Of the many challenges associated with organic production, education and certification are the two that can stop a farmer from making the transition before the other challenges are even

brought to light. Organic farming is known for being more knowledge-based than input based

and, therefore, requires more research and education for success than does conventional farming

(Zundel and Kilcher, 2007). With conventional farming techniques, external inputs such as

fertilizers and pesticides are a significant portion of management practices to ensure a high yield

and damage free crop. In organic farming, however, these external inputs are replaced with

knowledge inputs that challenge the grower to use skills and techniques that cannot be found by

applying a chemical to the crop (Scialabba, 2000). Furthermore, this knowledge is often difficult

for small-scale growers to acquire as most research done on the transition to organic farming has

been conducted using large-scale operations (HLPE, 2013). As a result, the information available

pertains to only a select number of growers interested in transitioning to organic farming,

causing the remaining parties to continue conventional farming.

In addition to education being a challenge for a farmer transitioning to organic,

certification is also a significant deterrent to making the conversion. During the first three years

of organic operations, farmers must adhere to all organic regulations and methods, but they are

not able to sell their products at the premium prices of organically certified as they have not yet

obtained their certification (Jouzi et al., 2017). As a result of not being able to sell products for

organic prices, this three-year transition period requires farmers to invest large amounts of

money into the process without seeing much return (Seufert, 2012). Certification is costly to

obtain and is only truly beneficial for farmers who can get their products into a profitable organic

market (Rundgren and Parrott, 2006). Making the transition to organic is costly and only

profitable in the long run for a select group of farmers who can enter the organic market.

Another challenge faced by farmers transitioning to organic growing is risk management.

As previously mentioned, external inputs such as fertilizers, pesticides, and other chemical

applications are not used in organic farming. Due to the strict regulations placed on organic operations, pests and soil health (problems relatively easily remedied in conventional farming operations) are more difficult to control as there are fewer solutions available for use that stay within said regulations (Jouzi et al., 2017). Although cost effective in the sense that money does not have to be spent purchasing these various chemicals, not applying said chemicals can lead to lower crop yields. Having and maintaining adequate nutrients in the soil is instrumental in producing high quality products. Nitrogen deficiency is the most prominent nutrient challenge seen in organic farming (Kirchmann et al., 2008). Additionally, not being able to apply most pesticides on organic products can lead to crop damage that can ruin the efforts and finances of a farmer. Though there are ways to apply nutrients to the soil, such as planting cover crops and using organic fertilizer, these methods take several years to build up the required nutrients to successfully produce a crop on par with conventionally grown crops (Watson et al., 2002). Not having a reliable way to protect crops from pests or ensure that crops are receiving all nutrients needed for them to grow, can easily keep farmers from transitioning to organic as the risks can feel too great to overcome.

Chapter 2

Lettuce cultivar selection in different vegetable growing systems

Introduction

Lettuce (*Lactuca sativa)* is grown across the entire U.S., which is ranked as the second largest lettuce producer in the world (FAOSTAT, 2015). In the southeastern U.S., lettuce is grown under various crop management practices and growing systems; thereby, lettuce cultivars are typically selected according to environmental conditions. For example, growers planting lettuce under open field conditions typically select heat-tolerant cultivars to reduce the potential for bolting and tipburn (Dufault et al., 2009; Lee et al., 2013); contrarily, lettuce cultivars for controlled environmental conditions should be selected according to growth characteristics and yield potential (Holmes et al., 2019). In both cases, the selected cultivar must provide a high-quality product to consumers with a lettuce head that will be visually appealing and highly palatable.

Lettuce grown under open field conditions might follow conventional or organic practices. Conventional practices comprise most southeastern U.S. growing systems, in which pesticides and synthetic fertilizers are frequently applied (Dufault et al., 2009; Wallace et al., 2010); while organic practices comprise a small portion of lettuce grown in the southeastern U.S. (Jayalath et al., 2017), in which lettuce is grown with no use of synthetic fertilizer or pesticides. Instead, growers rely on crop rotation and approved natural agents to provide adequate nutrient levels and prevent pests (Gheshm and Brown, 2018; Zandvakili et al., 2019). Regardless of crop management practices, lettuce grown under open field conditions is subjected to environmental factors, including weather variability, pests, and disease pressure. Cultivar selection must minimize the damage caused by these abiotic and biotic effects. Previous studies have demonstrated that cultivars resistant to heat

stress can maximize lettuce yield due to increased leaf area index and chlorophyll content (Kadir et al., 2017); while cultivars resistant to drought stress can increase plant growth, biomass accumulation, and yield during drought periods (Kreutz et al., 2021; Lafta et al., 2017). Also, lettuce cultivars with disease resistance, particularly to bacterial leaf spot, a common lettuce disease in the southeastern U.S., can increase yield and head quality in rainy seasons (Jayalath et al., 2017)

In the southeastern U.S., lettuce production under controlled environmental conditions is primarily in high tunnels and greenhouse hydroponic systems, which minimizes the challenges caused by the subtropical environmental conditions of the region (Sublett et al., 2018). High tunnels are not temperature-controlled systems, but covered structures that provide protection from environmental factors and selected pests and diseases; this improves crop quality and increases profitability (Rader and Karlsson, 2006; Wallace et al., 2012). Particularly, the yield and head quality of lettuce grown under high tunnel systems depend on the planting date and cultivar selection (Wallace et al., 2012). In hydroponic systems, precise control over growing conditions allows for a faster crop cycle that increases yields per unit area (Holmes et al., 2019; Sublett et al., 2018). The nutrient film technique (NFT) is the most common hydroponic system used for lettuce production in the southeastern U.S., which was previously reported to increase lettuce yield by 270% compared to open field conditions using conventional growing practices (Seginer, 1998). Yield increments in controlled environmental conditions are commonly associated with increased plant population and water and nutrient use efficiency (Korres et al., 2014). In addition, plants grown under controlled environmental conditions are not affected by weather variability of open field conditions (Dufault et al., 2009).

In recent years, the demand for healthier and more nutritious food options by consumers has led to the replacement of conventional open-field lettuce production with organic practices and the adoption of high tunnel and hydroponic systems. Particularly, conventional growing practices of open field conditions require a large volume of herbicides, pesticides, and supplemental nutrients to maximize yields (Wander et al., 1994; Durham and Mizik, 2021). The increasing costs of resources like water and land have resulted in higher expenses for growers to maintain high productivity, thereby exacerbating the situation (Durham and Mizik, 2021). Under this scenario, choosing the optimum cultivars for lettuce production based on the growing system is considered the primary best management practice for any farming operation. (Wallace et al., 2012; Langston et al., 2013; Lopez et al., 2017). Still, there is insufficient information available regarding cultivar comparison across growing systems for lettuce production in the southeastern U.S.

Thus, the objective of this study was to evaluate the performance of commercial lettuce cultivars for head weight and quality under different growing systems (i.e., conventional, organic, high tunnel, and hydroponic) in the southeastern U.S.

Materials and Methods

Experimental design. Field experiments were conducted in 2022 in a two-way factorial experimental design of a growing system and lettuce cultivar as the levels, and it was randomized in a split-plot arrangement. The growing system was the main plot, and the lettuce cultivar was the subplot. Subplots were arranged in a complete randomized block design with four replications within each growing system.

Growing system treatments consisted of 1) an open field treatment with conventional production growing practices (CONV), 2) an open field treatment with organic production growing

practices (ORG), 3) a high tunnel treatment with conventional production growing practices (HT), and 4) a hydroponic treatment with conventional production growing practices (HYDRO). Lettuce cultivar treatments are listed in Table 1, while Figure 1 gives a visual overview of cultivars separated by lettuce type.

Table 1. Cultivar, lettuce type, reported disease resistance, and evaluated growing systems.

Cultivar	Lettuce type	Growing system	Reported resistance
'Panisse'	Oakleaf	CONV, ORG, HT, HYDRO	DM, Nr, LMV
'Breen'	Romaine	CONV, ORG, HT	DM
'Coastal Star'	Romaine	CONV, ORG, HT, HYDRO	Rs
'Salanova Green Butter'	Salanova	CONV, ORG, HT, HYDRO	DM, Nr
'Salanova Red Butter'	Salanova	CONV, ORG, HT, HYDRO	DM, Nr
'Rouxai'	Oakleaf	CONV, ORG, HT, HYDRO	DM, Nr
'Monte Carlo'	Romaine	CONV, ORG, HT	DM
'Rosaine'	Bibb	CONV, ORG, HT, HYDRO	DM, Nr, Pb
'Newham'	Bibb	CONV, ORG, HT, HYDRO	DM, Nr, LMV, Pb, Rs
'Truchas'	Romaine	CONV, ORG, HT	DM, TBSV, LMV
'Dragoon'	Romaine	CONV, ORG, HT	DM, Nr, TBSV, LMV
'Grazion'	Oakleaf	CONV, ORG, HT, HYDRO	DM, Nr. Pb, LMV
'Bauer'	Oakleaf	CONV, ORG, HT, HYDRO	DM, Nr, TBSV, LMV
'Ezflor'	One-Cut	CONV, ORG, HT, HYDRO	DM, Nr, TBSV,
'Blue Rock'	Romaine	CONV, ORG, HT	DM, Nr, TBSV,
'Milagro'	Butterhead	CONV, ORG, HT	DM, Nr, TBSV, LMV

Growing system: CONV = Conventional production, ORG = Organic production, HT = High tunnel production, HYDRO = Hydroponic production.
Reported resistance: DM = Downy Mildew, LMV = Lettuce Mosaic Virus, Nr = Lettuce Leaf Aphid *Nasonovia ribisnigri*, Pb = Lettuce Root Aphid *Pemphigus bursarius*, Rs = Corky Root, TBSV = Tomato Bushy Stunt Virus.

Figure 1. Lettuce Varieties. Visual overview of lettuce cultivars evaluated in the present study separated by type. Cultivar of lettuces romaine type evaluated were 'Blue Rock' (A), 'Breen' (B), 'Coastal Star' (C), 'Dragoon' (D), 'Monte Carlo' (E), and 'Truchas' (F). Cultivars of lettuce oakleaf type evaluated were 'Bauer' (G), 'Rouxai' (H), 'Grazion' (I), and 'Panisse' (J). Cultivars of lettuce butterhead evaluated were 'Milagro' (K), 'Salanova Green Butter' (L), and 'Salanova Red Butter' (M). Cultivars of lettuce bibb type evaluated were 'Newham' (N) and 'Rosaine' (O). Cultivar of lettuce one-cut type evaluated was 'Ezflor' (P).

Sites description and crop management. The site characterization for each growing system is shown in Table 2.

Table 2. Site description and weather conditions for the conventional (CONV), organic (ORG), high tunnel (HT), and hydroponic (HYDRO) growing systems.

Site description	Growing system			
	CONV	ORG	HT	HYDRO
Soil type	Sandy loam	Loamy sand	Sandy loam	-
Beds spacing center to center	6 ft	6 ft	6 ft	-
Bed width	36 inch	36 inch	18 inch	-
Row number per bed or NFT	2	2	1	2
Plant in-row spacing	9 inch	9 inch	9 inch	8 inch
Plants per plot	20	20	10	20
Planting date	April 18, 2022	April 25, 2022	March 17, 2022	Aug. 15, 2022
Transplant date	May 6, 2022	May 27, 2022	April 12, 2022	Sep. 14, 2022
Harvest date	June 15, 2022	June 27, 2022	May 18, 2022	Oct. 14, 2022
Days from transplant to harvest	40	31	36	30
GDD accumulated[z]	1,303	1,146	1,490	600 - 900

NFT = Nutrient film technique
GDD = growing degree days
[z] GDD accumulated was calculated from transplanting date to harvest

In the CONV treatment, seedlings of lettuce cultivars were planted in 200 cell trays filled with soilless media (Pro-Mix BX; Premier Tech, Riviere-du-Loup, QC, Canada) and greenhouse-grown until transplanting. Lettuce cultivars were transplanted at the Plant Breeding Unit of the E.V. Smith Research and Extension Center at Auburn University located in Shorter, AL. Lettuce plants were transplanted in 36-inch-wide and 6-inch-tall, raised beds spaced at 6 ft center to center with a white-on-black impermeable film plastic mulch (Total Blockade; Berry Global Inc., Evansville, IN). Lettuce transplants were placed in double rows spaced at 16-in spacing with 9-in in-row spacing and a drip line irrigation system (30.48 cm (12 inches) emitter spacing, 1.89 L per min per 30.48 m at 68.95 kPa (0.5 gal per min per 100 ft at 10 psi); Chapin DLX; Jain USA, Haines City, FL) installed under the plastic mulching in the center of each bed. During the growing season,

irrigation events applied approximately 3.81 cm of water per week. Fertilizer application supplied

56.04 kg of N ha^{-1} using 10N-10P-10K (Rainbow Plant Food; Agrium, Tifton, GA) before laying

plastic mulch. A week after transplanting, plants were fertilized weekly until harvest through drip

irrigation with 16.81 kg of N ha^{-1} per week using 20N-20P-20K (Rainbow Plant Food; Agrium,

Tifton, GA). For insect control, 3 oz/acre of spinosad and 8 oz/a lambda cyhalothrin,

chlorantraniliprole (Besiege; Syngenta, Greensboro, NC) were applied on 05/20/22. For disease

control, 15.5 oz/acre of azoxystrobin (Abound; Syngenta, Greensboro, NC) was applied on

5/20/22, followed by 2. 24 kg ha^{-1} of copper sulfate (Cuprofix ultra40; UPL, King of Prussia,

Pennsylvania), on 6/2/022. On 6/3/22, 3.37 kg ha^{-1} of mancozeb (Manzate; UPL, King of Prussia,

Pennsylvania) and 2.24 kg ha^{-1} of copper sulfate (Cuprofix ultra40; UPL, King of Prussia,

Pennsylvania) were applied.

In the ORG treatment, seedlings of lettuce cultivars were planted in 200 cell trays filled

with soilless media (Miracle Grow Performance Organics; Marysville, OH) and greenhouse grown

until transplanting. Lettuce cultivars were transplanted at the Organic Unit of the E.V. Smith

Research and Extension Center from Auburn University, located in Shorter, AL. Similar to the

CONV treatment, lettuce plants for the ORG treatment were transplanted in 36-inch-wide and 6-

inch-tall raised beds spaced at the 6-ft center to center with a white-on-black impermeable film

plastic mulch (Total Blockade; Berry Global Inc., Evansville, IN). Lettuce transplants were placed

in double rows spaced at 16-in spacing with 9-in in-row spacing and a drip line irrigation system

(12-inch emitter spacing, 0.5 gal/min per 100 ft at ten psi; Chapin DLX; Jain USA, Haines City,

FL) installed under the plastic mulching in the center of the bed. Irrigation events applied

approximately 1.5 inches of water per week, while fertilizer application supplied 50 lb of N/acre

using 5N-4P-3K (Harmony; Environmental Products, Roanoke, VA.) before laying plastic mulch.

After transplanting, plants also received 15 lb of N/week/acre using 7N-7P-7K (Nature Safe; Darling Ingredients, Irving, TX). Two OMRI listed *Bacillus thuringiensis* insecticides for insect control at a rate of 1.5 oz/gallon of (Thuricide BT Caterpillar Control, Southern AG; Henderson, NC) on 6/10/2022 and 1.5 oz/gallon of (Dipel DF, Valent; San Roman, CA) on 6/22/2022. There was no application of fungicides in the ORG treatment.

In the HT treatment, seedlings of lettuce cultivars were planted in 200 cell trays filled with soilless media (Pro-Mix BX; Premier Tech, Riviere-du-Loup, QC, Canada) and greenhouse grown until transplanting. Lettuce cultivars were transplanted in a high tunnel (30 x 90 ft, Atlas Greenhouse; Alapaha, GA) at the Plant Breeding Unit of the E.V. Smith Research and Extension Center from Auburn University located in Shorter, AL. Lettuce plants were transplanted in 18-inch-wide and 6-inch-tall raised beds spaced at 6 ft center to center with a white-on-black, impermeable film plastic mulch (Total Blockade; Berry Global Inc., Evansville, IN). Lettuce transplants were placed in single rows with a 9-in in-row spacing and a drip line irrigation system (12-inch emitter spacing, 0.5 gal/min per 100 ft at ten psi; Chapin DLX; Jain USA, Haines City, FL) installed under the plastic mulching in the center of each bed. During the growing season, irrigation events applied approximately 1.5 inches of water per week. Fertilizer application supplied 56.04 kg of N ha^{-1} using 10N-10P-10K (Rainbow Plant Food; Agrium, Tifton, GA) before laying plastic mulch. A week after transplanting, plants were fertilized once a week until harvest through drip irrigation with 16.81 kg of N ha^{-1} per week using 20N-20P-20K (Rainbow Plant Food; Agrium, Tifton, GA). For insect control, 3 oz/acre spinosad and 8 oz/a lambda cyhalothrin, chlorantraniliprole (Besiege; Syngenta, Greensboro, NC) were applied on 04/22/22. For disease control, 15.5 oz/acre of azoxystrobin (Abound; Syngenta, Greensboro, NC) was applied on 04/29/22, followed by 2.24 kg ha^{-1} of copper sulfate (Cuprofix ultra40; UPL, King of Prussia,

Pennsylvania), on 5/6/022. On 5/12/22, 3.36 kg ha^{-1} of mancozeb (Manzate; UPL, King of Prussia, Pennsylvania), and 2.24 kg ha^{-1} of copper sulfate (Cuprofix ultra40; UPL, King of Prussia, Pennsylvania), were applied.

The HYDRO treatment was established on a commercial lettuce farm at the Eastern Shore of Virginia on August 18, 2022. Lettuce seeds of 16 cultivars were planted in 200-cell rockwool propagation trays with a humidity dome (Cropking Inc. Lodi, OH, USA), covered with a dark mat for 3 days and grown inside a greenhouse until ready for transplanting at 25 after seeding. Lettuce cultivars were transplanted in a greenhouse 8-foot heigh and 44-ft wide (Cropking Inc. Lodi, OH, USA), temperature controlled at 65°F and 75°F, using NFT with 10-ft long PVCnursery pipe channels and removable covers. Seedlings were transplanted at 8 inches of in-row spacing in single growing rails (channels). All channels were connected to a 100-gal reservoir that provided constant water and fertilizer flow through the growing channels. The growing solution was maintained at a pH of 5.9 with an electrical conductivity of 1.8 from transplanting to harvest. The concentration of individual nutrients was maintained at 150 ppm of N, 70 ppm of P, 150 ppm of K, 100 ppm of Ca and 50 ppm of Mg. Plants were sprayed once with BT (Bacillus Thuringiensis) for lepidoptera control at 10 days after transplanting. No further pesticide applications were done.

Data collection. Weather conditions of daily air temperature and rainfall events were recorded using an on-site weather station (WatchDog Wireless Station, WD Wireless ET Weather Station, LTE-M 50500102) for the CONV and ORG treatment, a temperature meter (HOBO Pendant® Temperature/Light 64K Data Logger, Onset Computer Corporation, Bourne, MA) for the HT

treatment, and an integrated commercial thermostat controlled the air temperature for the HYDRO treatment.

Under all growing systems, lettuce growing degree days (GDD) were calculated by subtracting the lettuce base air temperature of 7°C from the daily average air temperature (Kristensen et al., 1987). Cumulative degree days from transplanting to harvest were then calculated as the sum of daily degree days.

All lettuce cultivars were harvested on the same day within each growing system by cutting heads at the base of each plant. Lettuce heads were individually weighed, and head diameter and height were measured. Before harvesting, the leaf chlorophyll concentration (SPAD) of three random leaves from five plants of each plot was measured using a soil plant analysis development chlorophyll meter (SPAD 502 Plus Chlorophyll Meter, Spectrum Technologies, Inc., Aurora, IL).

Statistical analysis. All data were analyzed using linear mixed techniques implemented in SAS PROC GLIMMIX (SAS/STAT 14.2; SAS Institute Inc., Cary, NC). Lettuce head weight, height, diameter, and SPAD were analyzed with growing system treatments, cultivar treatments, and their interaction as fixed effects. Block within each growing system was considered a random effect. When the *F* value of the ANOVA was significant, least-square mean comparisons using the Tukey adjust were performed at a *P* value of 0.05. Means were portioned as required utilizing the slice command in SAS.

Results

Weather conditions. Weather conditions of rainfall and daily maximum, minimum, and average air temperature for the CONV, ORG, and HT treatments are presented in Figure 2. Daily air temperature for the HYDRO treatment was maintained between 18° C and 24° C.

Rainfall events had no impact on HYDRO and HT treatments since they are closed systems. Contrarily, rainfall events accumulated 10.03 cm in the CONV treatment and 2.24 cm in the ORG treatment. Daily air temperature averaged 22°C for CONV, 23°C for ORG, and 26°C for HT. Daily maximum air temperature averaged 37°C for CONV, 37°C for ORG, and 38°C for HT, while daily minimum air temperature averaged 11.3°C for the CONV treatment, 11°C for ORG, and 15°C for HT. Particularly, there was a high fluctuation range of daily maximum and minimum air temperature within the HT treatment (Fig. 2), caused by the opening and closing of side walls. Accumulated GDD for each growing system was 1,303 for CONV, 1,146 for ORG, 1,490 for HT, and ranged from 600 to 900 for HYDRO.
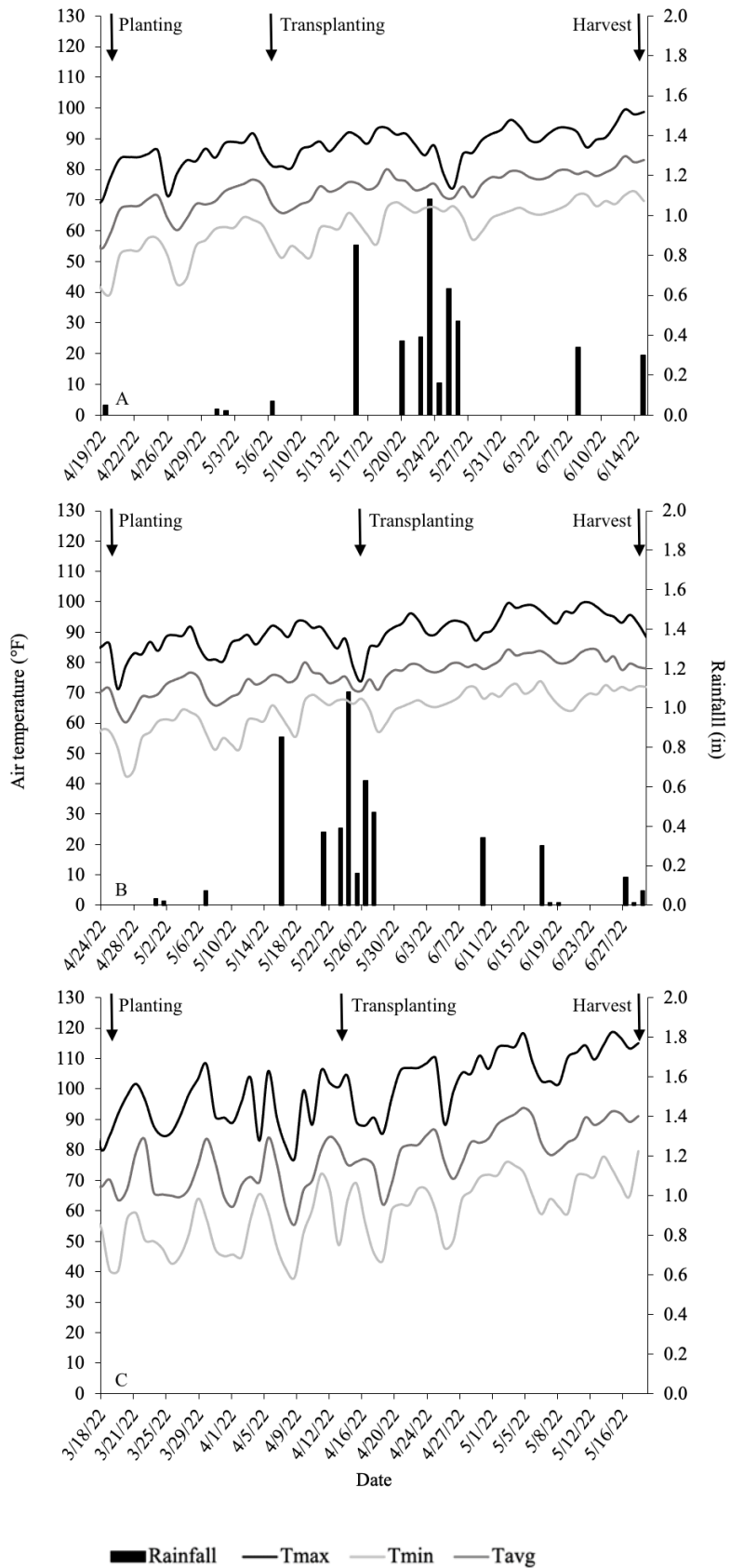
Figure 2. Weather Conditions for Lettuce Growing Season. Weather conditions of daily maximum, minimum, and average temperature (°F), and rainfall events (inch) during lettuce growing season of the open field conditions with conventional production growing practices treatment (A), open field conditions with organic production growing practices treatment (B), high tunnel conditions with conventional production growing practices treatment (C). (1.8 x °C) + 32 = °F; 1 mm = 0.0394 inch.

Lettuce yield. Lettuce head weight was significantly affected by the interaction between the cultivar and the growing system (Table 3).

Table 3. Interaction effect between lettuce cultivar and growing system treatments on lettuce head weight.

Cultivar	Growing system						
	Conventional		High Tunnel		Hydroponic		Organic
	Lettuce Head Weight (lb)						
'Bauer'	0.48	bcd[z] A[y]	0.41	bcd A	0.32	ab AB	0.14	def B
'Bluerock'	0.79	a A	0.71	a A	-		-	
'Breen'	0.41	bcd A	0.53	abc A	-		0.47	abc A
'Coastal Star'	0.55	bc A	0.54	abc A	0.29	bc B	0.24	cde B
'Dragoon'	0.64	ab A	0.60	ab A	-		0.11	f B
'Ezflor'	0.37	cd A	0.34	cd A	0.25	bc A	0.29	cd A
'Grazion'	0.68	ab A	0.49	bc A	0.47	a AB	0.23	cde B
'Milagro'	0.55	bc A	0.52	abc A	-		0.13	ef B
'Monte Carlo'	0.50	bc A	0.36	bcd B	-		0.54	ab A
'Newham'	0.53	bc A	0.55	abc A	0.24	bc B	0.18	def B
'Panisse'	0.48	bcd A	0.56	abc A	0.39	ab A	0.31	bc A
'Rosaine'	0.38	bcd A	0.41	bcd A	0.19	c B	0.21	cdef AB
'Rouxai'	0.32	cd A	0.31	d A	0.24	bc A	0.22	cde A
'Salanova Green Butter'	0.34	cd A	0.36	bcd A	0.35	ab A	0.15	def B
'Salanova Red Butter'	0.22	d A	0.26	d A	0.23	bc A	0.22	cde A
'Truchas'	0.30	cd B	0.38	bcd B	-		0.68	a A

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For the main effect of the cultivar within the growing system, the cultivar 'Bluerock' had the largest head weight within CONV (0.36 kg/head) and HT (0.32 kg/head); while cultivar 'Salanova Red Butter' had the lowest head weight within the CONV (0.10 kg/head) and HT (0.12 kg/head) growing systems. Particularly, the cultivar 'Bluerock' was not grown in the HYDRO growing system and did not perform well in the ORG system; hence, heads were not harvested in these two systems. For the ORG treatment, cultivar 'Truchas' (0.31 kg/head) had the highest lettuce head weight, while 'Dragoon' (0.5 kg/head) had the lowest. For the HYDRO growing system, 'Grazion' (0.21 kg/head) had the highest lettuce head weight and 'Rosaine' (0.09 kg/head) the lowest.

For the main effect of the growing system within a cultivar, the CONV and HT growing systems had the highest lettuce head weight compared to ORG and HYDRO within most of the cultivars, except for 'Breen,' 'Monte Carlo,' 'Salanova Green Butter,' 'Salanova Red Butter,' and 'Truchas.' Cultivar 'Breen' was not grown in the HYDRO growing system, and there was no significant difference among CONV, HT, and ORG within cultivar 'Breen' for lettuce head weight. Cultivar 'Monte Carlo' was not grown in the HYDRO either; however, lettuce head weight was higher when 'Monte Carlo' was grown in the ORG (0.24 kg/head) and CONV (0.23 kg/head) treatments compared to HT (0.16 kg/head). For cultivar 'Salanova Green Butter', the highest head weight was measured in the HT (0.16 kg/head) and HYDRO (0.16 kg/head) treatments, and the lowest head weight was measured in ORG (0.07 kg/head). Similarly, 'Salanova Red Butter' had the highest head weight within HT (0.12 kg/head) and HYDRO (0.10 kg/head) growing systems.

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For cultivar 'Truchas', lettuce head weight was the highest in the ORG (0.31 kg/head) and HT (0.17 kg/head) growing systems. 'Truchas' was not grown in the HYDRO treatment.

Head quality. Lettuce head quality parameters evaluated were SPAD, head diameter, and head height, which were all impacted by a significant interaction between the cultivar and growing system (Tables 4, 5, and 6).

Table 4. Interaction effect between lettuce cultivar and growing system treatments on lettuce SPAD.

Cultivar	Growing system						
	Conventional		High Tunnel		Hydroponic		Organic
	SPAD						
'Bauer'	31.3	c[z] AB[y]	34.8	c A	27.0	d B	35.4	cd A
'Bluerock'	38.9	abc A	49	ab A	-		-	
'Breen'	39.9	ab A	47.8	ab A	-		41.9	abc A
'Coastal Star'	36.6	bc AB	42.9	abc A	30.8	bc B	43.5	abc A
'Dragoon'	41.1	ab A	48.4	ab A	-		44.7	ab A
'Ezflor'	35	bc AB	37.6	c AB	29.5	cd B	42.9	abc A
'Grazion'	38.8	abc A	38	bc A	46.9	a A	44	ab A
'Milagro'	34.8	bc AB	33.4	c B	-		44	ab A
'Monte Carlo'	42.9	ab A	46.7	ab A	-		38.4	cd A
'Newham'	45	a A	49.9	a A	32.9	bc B	33.7	cd B
'Panisse'	19.7	d B	20.7	c B	23.8	d B	39.5	bc A
'Rosaine'	39.3	abc A	45.5	ab A	31.5	bc B	30.6	d B
'Rouxai'	35.7	bc A	34.9	c A	22.7	d B	38	cd A
'Salanova Green Butter'	46.1	a A	44.5	abc A	38.3	ab AB	32.6	cd B
'Salanova Red Butter'	43.8	ab AB	49	ab A	38.2	ab AB	37	cd B
'Truchas'	43.8	ab A	44.9	abc A	-		49.4	a A

[z] Values followed by the same lowercase letter within growing system (column) indicates no significant differences (P < 0.05) among cultivar (row) according to Tukey test.

[y] Values followed by the same uppercase letter within cultivar (row) indicates no significant differences (P < 0.05) among growing system (column) according to Tukey test.

Table 5. Interaction effect between lettuce cultivar and growing system treatments on lettuce head diameter.

Cultivar	Growing system			
	Conventional	High Tunnel	Hydroponic	Organic
	Lettuce head diameter (in)			
'Bauer'	9.1 cde[z] A[y]	8.8 cd A	8.2 a A	8.2 cd A
'Bluerock'	13.0 a A	12.6 a A	-	-
'Breen'	9.5 cd A	9.2 bcd A	-	11.1 a A
'Coastal Star'	12.1 ab A	12.7 a A	8.4 a B	8.9 abc B
'Dragoon'	8.4 de A	9.0 bcd A	-	8.8 bc A
'Ezflor'	9.8 cd A	9.9 bcd A	10.7 a A	9.9 ab A
'Grazion'	11.5 abc AB	12.6 a A	9.2 a C	9.5 abc BC
'Milagro'	9.4 cde A	10.2 bc A	-	8.4 bcd A
'Monte Carlo'	11.0 bc A	9.8 bcd A	-	11.2 a A
'Newham'	8.3 de AB	8.7 cd AB	9.3 a A	6.7 d B
'Panisse'	10.7 bcd A	11.1 ab A	9.6 a A	10.8 ab A
'Rosaine'	9.3 cde A	8.6 cd A	9.7 a A	9.9 abc A
'Rouxai'	9.6 cd A	9.9 bcd A	10.8 a A	8.0 cd A
'Salanova Green Butter'	8.6 de A	8.5 cd A	9.1 a A	8.2 cd A
'Salanova Red Butter'	7.6 e B	7.9 d B	9.1 a AB	10.5 ab A
'Truchas'	10.3 bcd A	8.5 cd A	-	8.9 abc A

[z] Values followed by the same lowercase letter within growing system (column) indicates no significant differences (P < 0.05) among cultivar (row) according to Tukey test.
[y] Values followed by the same uppercase letter within cultivar (row) indicates no significant differences (P < 0.05) among growing system (column) according to Tukey test.

Table 6. Interaction effect between lettuce cultivar and growing system treatments on lettuce head height.

Cultivar	Growing system			
	Conventional	High Tunnel	Hydroponic	Organic
	Lettuce head height (in)			
Bauer	5.2 de^z B^y	5.3 d B	5.1 d B	7.2 efg A
Bluerock	12.0 a A	10.2 a A	-	-
Breen	8.0 b B	7.8 bc B	-	11.3 ab A
Coastal Star	12.0 a A	9.2 ab B	11.9 a A	8.0 defg B
Dragoon	7.1 bcd A	6.8 cd A	-	7.7 efg A
Ezflor	7.2 bc B	6.1 cd B	6.1 cd B	9.0 cd A
Grazion	8.2 b AB	7.2 c B	9.4 b A	8.2 cdef AB
Milagro	7.1 bcd A	5.8 cd A	-	7.5 efg A
Monte Carlo	8.0 b B	6.8 cd B	-	10.1 bc A
Newham	6.8 bcd A	6.4 cd A	6.8 c A	6.1 fg A
Panisse	6.9 bcd B	6.6 cd B	5.4 cd B	10.3 abc A
Rosaine	7.1 bcd B	5.7 cd B	6.1 cd B	9.3 cd A
Rouxai	6.8 bcd A	5.9 cd A	5.8 cd A	6.2 fg A
Salanova Green Butter	5.7 cde A	5.3 d A	6.4 cd A	5.8 g A
Salanova Red Butter	5.0 e B	5.3 d B	6.4 cd B	8.9 cde A
Truchas	8.1 b A	6.2 cd B	-	12.4 a A

^{z} Values followed by the same lowercase letter within growing system (column) indicates no significant differences (P < 0.05) among cultivar (row) according to Tukey test.

^{y} Values followed by the same uppercase letter within cultivar (row) indicates no significant differences (P < 0.05) among growing system (column) according to Tukey test.

For the main effect of cultivar within the growing system on lettuce SPAD (Table 4), cultivar 'Newham' had the highest SPAD within CONV (45.0) and HT (49.9), while 'Panisse' had the lowest SPAD within CONV (19.7) and HT (20.7) growing systems. Cultivar 'Grazion' had the highest SPAD within HYDRO (46.9), while cultivar 'Rouxai' had the lowest SPAD within HYDRO (22.7). Under the ORG growing system, 'Truchas' (49.4) had the highest SPAD, while 'Rosaine' (30.6) had the lowest SPAD.

Regarding the main effect of the growing system within cultivar for lettuce SPAD, the CONV, ORG, and HT growing systems had higher lettuce SPAD compared to HYDRO, except for 'Grazion', 'Salanova Green Butter', and 'Salanova Red Butter' that had no significant difference among treatments.

For the main effect of cultivar within the growing system on head diameter (Table 4), cultivar 'Bluerock' (33.02 cm) had the highest head diameter within the CONV growing system. In contrast, cultivar 'Salanova Red Butter' (19.30 cm) had the lowest. 'Coastal Star' (32.26 cm) and 'Salanova Red Butter' (19.30 cm) had the highest and lowest head diameter within the HT growing system, respectively. Cultivar 'Rouxai' (27.43 cm) had the largest head diameter within HYDRO, while 'Bauer' (20.83 cm) had the smallest head diameter within HYDRO. Ultimately, cultivar 'Monte Carlo' had the largest head diameter within ORG (28.45 cm) and cultivar 'Newham' (17.02 cm) the smallest.

Regarding the main effect of the growing system within a cultivar, the CONV growing system had the largest head diameter within cultivars 'Bauer' (23.11 cm), 'Bluerock' (33.02 cm), and 'Truchas' (26.16 cm); while CONV had the smallest head diameter within the cultivars 'Dragoon' (21.34 cm), 'Ezflor' (24.90), and 'Salanova Red Butter' (19.30 cm). The HT growing system had the largest head diameter within the cultivars 'Coastal Star' (32.26 cm), 'Dragoon' (22.90 cm), 'Grazion' (32.00 cm), 'Milagro' (25.91 cm), and 'Panisse' (28.19 cm); while HT had the smallest head diameter within the cultivars 'Bluerock' (32.00 cm), 'Breen' (23.37 cm), 'Monte Carlo' (24.90 cm), 'Rosaine' (21.84 cm), and 'Truchas' (21.60 cm). The HYDRO growing system had the largest head diameter within the cultivars 'Ezflor' (27.18 cm), 'Newham' (23.62 cm), 'Rouxai' (27.43 cm), and 'Salanova Green Butter' (23.11 cm); while HYDRO had the smallest head diameter within cultivars 'Coastal Star' (21.34 cm), 'Grazion' (23.37 cm), and 'Panisse'

(24.38 cm). The ORG growing system had the largest head diameter within cultivars 'Breen' (28.19 cm), 'Monte Carlo' (28.45 cm), 'Rosaine' (25.15 cm), and 'Salanova Red Butter' (26.67 cm); while ORG had the smallest head diameter within cultivars 'Milagro' (21.34 cm), 'Newham' (17.02 cm), 'Rouxai' (20.32 cm), and 'Salanova Green Butter' (20.83 cm).

For the main effect of cultivar within the growing system on head height (Table 5), cultivars 'Bluerock' (30.48 cm) and 'Coastal Star' (30.48 cm) had the greatest head height within the CONV growing system. In contrast, cultivar 'Salanova Red Butter' (12.7 cm) had the lowest. Cultivar 'Bluerock' (25.91 cm) also had the greatest head height within HT. In contrast, cultivars 'Bauer' (13.46 cm), 'Salanova Green Butter' (13.46 cm), and 'Salanova Red Butter' (13.46 cm) had the lowest head height within HT. Cultivar 'Coastal Star' (30.23 cm) had the greatest head height within HYDRO, while cultivar 'Bauer' (12.95 cm) had the lowest head height. 'Truchas' (30.50 cm) had the greatest head height within the ORG growing system; while cultivar 'Salanova Green Butter' (14.73 cm) had the lowest head height within ORG.

Regarding the main effect of the growing system within a cultivar, the ORG growing system had the greatest head height compared to CONV, HT, and HYDRO growing systems within all cultivars except for cultivars 'Bluerock', 'Coastal Star', 'Grazion', 'Newham', 'Rouxai', and 'Salanova Green Butter'. As aforementioned, the 'Bluerock' was not grown in the HYDRO growing system and did not perform well in the ORG system, so heads were not harvested. However, 'Bluerock' had the greatest head height within CONV (30.48 cm) and HT (25.91 cm) growing systems. For 'Coastal Star', lettuce head height was the greatest within CONV (30.48 cm) and the lowest within ORG (20.32 cm). Head highest was the greatest within HYDRO (23.88 cm) and the lowest within HT (18.29 cm) for cultivar 'Grazion'. For the cultivar 'Newham', lettuce head height was the greatest within CONV (17.27 cm) and HYDRO (17.27 cm), and the lowest

head height of 'Newham' was measured within ORG (15.49 cm). Cultivar 'Rouxai' had the greatest head height within CONV (17.27 cm) and the lowest within HYDRO (14.73 cm). Cultivar 'Salanova Green Butter' had the greatest head height within HYDRO (16.26 cm) and the lowest head height within HT (13.46 cm) growing system.

Discussion

Weather conditions directly impact lettuce growth and head quality (Harwood et al., 2010; Wheeler et al., 1993). Rainfall events are the most common weather parameter to impact vegetable production in the southeastern U.S. (da Silva et al., 2020; Fraisse et al., 2010; Coolong et al., 2022), including lettuce (Wallace et al., 2012). In this study, rainfall events were only present in the CONV and ORG treatments; rainfall was well distributed during the growing season of these systems and had no influence on lettuce head weight and head quality. Contrarily, lettuce head weight and quality were significantly influenced by the daily air temperature. The optimum daily air temperatures for lettuce production range from 16°C to 25°c, with yield losses only observed when the average air temperature exceeds 29°C and night temperatures are higher than the optimum range (Lafta et al., 2017; Marklein et al., 2020). For CONV, ORG, and HT treatments, daily average air temperatures were within the optimum range for lettuce production. Still, there was a high variation between daily maximum and minimum air temperatures compared to the HYDRO, in which air temperatures were controlled within that optimum range for lettuce production (Lafta et al., 2017). Variations between the daily minimum and maximum air temperatures can directly impact GDD accumulation, which probably influenced lettuce growth and head weight (Dufault et al., 2009; Holmes et al., 2019).

Days from transplanting to harvest significantly impacted the accumulation of GDD, with the lowest GDD accumulation observed in HYDRO, followed by ORG, HT, and CONV. The accumulation of GDD has been shown by previous studies to have a positive correlation with lettuce head weight, which in turn drives the number of leaves, plant height, and leaf area index in lettuce (Kaur et al., 2017a; Kaur et al., 2017b; Dufault et al., 2009; Wang et al., 2008). In accordance, the CONV and HT growing systems had the highest lettuce head weight.

The relationship between GDD and lettuce growth is also affected by cultivar and negatively impacted by poor nutrient availability (Pavlou et al., 2007), which may explain the lower head weight of some cultivars in the ORG treatment compared to CONV and HT, despite the similar GDD accumulation in these systems. Synthetic fertilizers are more readily available for plants to uptake and provide better lettuce growth than organic fertilizers (Pavlou et al., 2007; Spehia et al., 2018). Organic fertilizers usually have a slow release of nutrients and may have impacted soil nutrient availability during the short season of lettuce (Ogles et al., 2015; Pavlou et al., 2007). In addition, while not evaluated in this study, weeds, one of the most significant challenges in organic production, were present in the ORG treatment, competing for nutrients and water and possibly impacting lettuce growth and head weight (Kruse and Nair, 2016; Wedryk et al., 2012).

Controlled environmental conditions are reported to increase lettuce yield compared to open field conditions due to a higher water and nutrient use efficiency; however, the increased yield of hydroponic systems is dependent on plant density in the greenhouse, nutrient management, cultivar, and pest management (Kaur et al., 2017b; Spehia et al, 2018). In this study, fertilizer and pest management in the HYDRO treatment followed recommendations from the Virginia Cooperative Extension, and no nutrient or disease and pest stresses were observed during the

season. The lower head weight observed in the HYDRO treatment, as compared to CONV and HT, could be attributed to the lower daily air temperatures that resulted in a decrease in GDD accumulation. However, the effects of the lower temperatures were mitigated by the shorter time from transplanting to harvest, which was 6 to 10 days shorter in the HYDRO treatment.

Regarding cultivar recommendations within each growing system, cultivar 'Bluerock' had the highest head weight in the CONV growing system with no significant difference from 'Dragoon' and 'Grazion'. For the ORG growing system, 'Truchas' was the lettuce cultivar with the highest head weight; however, 'Truchas' had no significant difference from 'Monte Carlo' and 'Breen'. These cultivars should be considered adapted to growing organically, given the challenges of organic production (Kruse and Nair, 2016; Ogles et al., 2015; Pavlou et al., 2007; Wedryk et al., 2012). For the HT growing system, cultivars 'Bluerock', 'Breen', 'Coastal Star', 'Milagro', 'Newham', and 'Panisse' had the highest head weight. Ultimately, cultivars 'Grazion', 'Panisse', 'Salanova Green Butter', and 'Bauer' had the highest head weight in the hydroponics treatment and could be considered cultivars that are well adapted to growth in a hydroponics system.

The cultivar recommendations in this study were limited to the head weight factor only. However, it is crucial for growers to take into account that wholesalers or direct markets demand high-quality lettuce heads, and cultivar selection should cater to the buyers' demand, which usually requires more than one type of lettuce. The type of lettuce of each cultivar is listed in Table 1, and the visual overview of each cultivar is shown in figure 1, which should help growers to attend to their market. Overall, daily air temperature plays an important role in lettuce production, and cultivar selection must ensure the cultivar is adaptable to the growing system characteristics (Dufaut et al., 2006; Holmes et al., 2019; Jayalath et al., 2017; Rader and Karlsson, 2006; Wallace et al., 2012).

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Chapter 3

Land use in the first year of organic transition for vegetable production

Introduction

Organic vegetable production in the U.S. has steadily increased in recent years due to market demand for nutritious and healthy produce. Currently, organic crops are grown on 3.6 million acres in U.S. with only 276 acres of organic fields in Alabama, where the top vegetable crops being organically grown include tomatoes, sweet potatoes, peppers, okra, and squash (USDA, 2019; Skorbiansky, 2023). In the southeastern U.S., including Alabama, challenges associated with vegetable production are mostly due to the environmental conditions of the region, where disease and pests are potentiated by the hot and humid climate, weeds compete with the cash crop during the entire growing season, and coarse textured soils impact nutrient and water availability for plants (Briar et al., 2011; Corbin et al.,; 2010; Jokela and Nair, 2016; Wedryk et al., 2012). Furthermore, the large acreage of conventional production systems in the region leads to heavy spraying programs that create insect, disease, and weed resistance to potential organic products, which are already limited compared to chemicals sprayed in conventional fields (Candian et al., 2021). Consequently, organic production requires changes in crop management practices, increased labor, and decreased yields that most of the time are counterbalanced by the high value of organic products (Bello, 2008; Smith et al., 2019; Jouzi et al., 2017).

Transitioning from conventional to organic crop production is a challenge for growers and takes a mandatory 3-year period, when there is a high likelihood of failure due to the challenges of production in the southeastern U.S. (Hanson et al., 2004). Currently, there is a lack of knowledge on crop management practices for the initial years of organic transition (Larkin et al., 2011; Wedryk et al., 2012). Most growers look for high profits and try to grow cash crops in

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the first year of transition, an approach that increases the likelihood of failure since vegetables cannot be sold with the high premium value of certified organic during the transitioning period. Growers must strategically plan crop production during the transitioning period to overcome the challenges of the southeastern U.S. and create and maintain soil health while mitigating the spread of weeds, pests, and disease.

The first approach to overcome challenges during the transitioning period is the use of cover crops. Planting cover crops before transitioning to organic production can help improve soil health and reduce weed pressure (Mirsky et al., 2013; Soti and Racelis, 2020). Particularly, cover crops have been reported to improve soil fertility and mitigate the occurrence of pests during the transition to organic production (Zinati, 2022; Ngouajio & McGiffen, 2003). When selecting cover crops for organic production, it is important to consider the goals of the cover crop, the climate and soil conditions, and the rotation schedule. Cover crops should be selected based on their ability to meet specific production goals, such as improving soil health or suppressing weeds (Ngouajio & McGiffen, 2003). Sorghum, a warm-season grain crop, has many benefits as a cover crop when transitioning to organic production, including reduction of soil erosion, improving soil health, and suppressing weeds (Blanco-Canqui & Lal, 2009). Additionally, sorghum is well adapted to hot and dry conditions and is particularly useful in areas with limited water resources, as it is drought tolerant (Krupa et al., 2017).

Another approach to success in the first year of transition is to promote continuous tillage. Tillage is a common practice used for soil preparation, in which the soil surface is loosened for aeration, incorporation of organic matter, and removal of weeds (Blanco-Canqui and Lal, 2009). However, the benefits and drawbacks of continuous tilling during organic transition are widely debated. Peigné et al. (2007) reported that tillage controls weeds during

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organic transition without negatively impacting soil compaction and water availability.

Contrarily, tillage was reported to reduce water holding capacity in the soil and increase soil

carbon sequestration during the organic transition (Dao, 1993). Overall, tillage is a strategy that

reduces weed pressure and can be an option for areas with severe weed pressure (Jokela and

Nair, 2016).

Ultimately, allowing an organic transitioning area to fallow in the first year of transition

may be another option to minimize the chances of failure. Klonsky and Greene (2005) reported

that letting land fallow before transitioning to organic production can help improve soil quality

and reduce the occurrence of weeds. In areas where vegetables have been growing under

conventional crop management practices, letting land fallow for a year can help reduce soil-

borne diseases and improve crop yield (Klonsky and Greene, 2005).

More and more growers have been transitioning to organic production, mostly due to

consumers' awareness of the relationship between nutrition and health after COVID-19.

However, there are no guidelines to assist growers during the transitioning period. We

hypothesize that the use of a cover crop, tillage, or letting land fallow in the first year of organic

transition will reduce the weed population and improve soil health parameters compared to the

growing of tomatoes as a cash crop. Thus, the objective of this study was to determine the

benefits of alternative use of land for the first year of organic transition for vegetable production.

Materials and Methods

Site description. Field experiments were conducted in the first year of a transitioning area at the

Organic Unit of the E.V. Smith Research and Extension Center (32° 26'54" N, 85° 54' 14" W)

from Auburn University located in Shorter, AL. The area is characterized as a humid subtropical

climate with frequent rainfall events during the summer and cool dry period in the winter (McNulty). Soil in the research area is classified as Cahaba sandy loam soil (a fine-loamy, siliceous, semiactive, thermic Typic Hapludults) with organic matter content of 0.5%, pH of 6.5, and low water holding capacity (USDA, 2014).

Experimental design. Four land use treatments were evaluated as strategies for the first year of organic transition. Land use treatments included a cover crop treatment, a tillage treatment, a fallow ground treatment, and a treatment growing tomatoes, which were arranged in a complete randomized block design (r = 4).

The cover crop treatment consisted of the growing of sorghum Sudan (Certified Organic AS 6201 Sorghum Sudan; Byron Seeds LLC, Rockville, IN), planted into a tilled area using a 1.5 m. Hedge plot planter at a rate of 67.24 kg ha^{-1}. A single fertilizer application of 80.7 kg of N ha^{-1} using 5N-4P-3K (Harmony; Environmental Products, Roanoke, VA) was used at pre-plant to ensure plant establishment. The tillage treatment consisted of bi-weekly tilling using a 5 m disc harrow for 85 days. The fallow ground treatment consisted of a non-disturbed area for 85 days. The growing tomato treatment consisted of using organic crop management practices to grow tomatoes as a cash crop. Plots from each treatment were 6 m wide and 15 m long (90 m^2).

In the growing tomato treatment, seedlings of tomato cultivar "Patsy" were planted in 200 cell trays filled with soilless media (Miracle Grow Performance Organics; Marysville, OH) and greenhouse grown until transplanting. Tomato seedlings were transplanted on 05/09/2022 in 1 m wide and 16 cm tall, raised beds spaced at 2 m center to center with a white-on-black totally impermeable film plastic mulch (Total Blockade; Berry Global Inc., Evansville, IN). Transplants were placed in single rows spaced at 45 cm in-row spacing and a drip line irrigation system (30

cm emitter spacing, 1.9 L min^{-1} per 30.48 m at 68.95 kPa; Chapin DLX; Jain USA, Haines City,

FL) installed under the plastic mulching in the center of the bed. Irrigation events applied

approximately 3.81 cm of water per week, while fertilizer application supplied 56.04 kg of N ha^{-1}

using 5N-4P-3K (Harmony; Environmental Products, Roanoke, VA.) prior to laying plastic

mulch. Tomato plants received an additional of 16.81 kg of N ha^{-1} per week using 7N-7P-7K

(Nature Safe; Darling Ingredients, Irving, TX) after transplanting, for a total of 81.65 kg of

nitrogen. Tomatoes were scouted weekly for insects, diseases and weed population during the

growing season. Tomatoes were treated with two OMRI listed *Bacillus Thuringiensis*

insecticides at a rate of 11.72 ml/L of (Thuricide BT Caterpillar Control, Southern AG;

Henderson, NC) and (Dipel DF, Valent; San Roman, CA) on 31 and 45 days after transplanting,

respectively. No disease was scouted during the growing season.

Weather parameters. Weather conditions of daily maximum, minimum, and average air

temperature and rainfall events were recorded during the period of the experiment using an on-

site weather station (WatchDog Wireless Station, WD Wireless ET Weather Station, LTE-M

50500102).

Soil physics parameters. Soil health parameters consisted of soil compaction, soil bulk density

(Bd), and soil water parameters, such as permanent wilting point (PWP), field capacity (FC),

saturation (SAT), and available water (AW). Soil health parameters were evaluated at the

beginning of the experiment (i.e., before treatment implementation) and at the end of the

experiment (i.e., at tomato harvest). A single soil sample collected at 15 cm and 30 cm soil depth

before initiating the experiment determined the baseline of soil physics parameters, which

characterized the area with a 3247 kPa of compaction. For the 15 cm soil depth, the area was characterized by 0.07 m³ m⁻³ at PWP, 0.24 m³ m⁻³ at FC, 0.34 m³ m⁻³ at SAT, 0.17 m³ m⁻³ of AW, and bulk density of 1,45 g cm⁻³. For the 30 cm soil depth, the area was characterized by 0.08 m³ m⁻³ at PWP, 0.26 m³ m⁻³ at FC, 0.36 m³ m⁻³ at SAT, 0.18 m³ m⁻³ of AW, and bulk density of 1,61 g cm⁻³. Soil samples collected at the end of the experiment allowed for land use treatments comparison.

Soil compaction was measured using a soil compaction meter (FieldScout SC900 Soil Compaction Meter; Spectrum Technologies, inc.) connected to a GPS. Samples were collected in the top 30 cm of soil using a grade of 1.5 m x 1.5 m within each plot, except for the tomato treatment, where samples were collected only in tomato beds at a grade of 0.5 m x 1.5 m. Soil PWP, FC, SAT, and AW were measured using soil water retention curves, in which undisturbed soil cores (5 cm diameter by 5 cm height) were sampled at 15 cm and 30 cm soil depth for each plot. Soil water retention curves were determined from each core throughout the evaporation method (Terleev et al., 2010) using a UMS-HYPROP2 and WP4-C (Meter Group, Inc., Pullman, WA, US). The matric potential and volumetric water content was fitted using the van Genuchten (1980) equation as below and described by Nascimento et al (2018).

$$\theta = \theta r + \frac{\theta s - \theta r}{\left[1 + (\alpha \varPsi)^n\right]^{1-1/n}} \tag{1}$$

where θ is the actual soil water content (m³ m⁻³), θr and θs are residual and saturated water content (m³ m⁻³), α is related to the inverse of the air entry pressure (m⁻¹), $\varPsi$ is the soil matric potential, and n is a measure of the pore size distribution (-). Finally, soil FC and PWP were assumed at a $\varPsi$ of -33 kPa and -1,500 kPa for all samples, respectively. Soil AW was calculated subtracting FC by PWP.

After the soil water retention curve determination, undisturbed soil cores were oven-dried at 65°C for 48 h and dry soil bulk density (Bd) was determined.

Weed population. The number of weeds was measured 5 times in all plots at 28, 45, 52, 60, and 76 days after tomato transplanting. Samples consisted of hand counting weeds in a 1 m² area, randomly selected within each plot. Weeds were separated according to species and the total number of weeds in each plot was calculated as the sum of all species.

Tomato crop. During the tomato growing season, diseases and insects were scouted weekly. Insects were hand counted and identified in a 1 m² area randomly selected in each plot and insects identified. Tomato diseases were scouted in the entire plot; however, no disease was observed. At maturity, tomato fruits were harvested in the center 15 plants of each plot. Harvests were conducted at 70 and 84 days after transplanting and fruit were graded and weighed according to USDA standards in extra-large (> 6.99 cm), large (6.35 cm to 7.06 cm), medium (5.72 cm to 6.42 cm), small (5.4 cm to 5.79 cm), and culls (i.e., misshapen, insect damage, or disease fruit) (USDA, 1997). Marketable yields were considered extra-large, large, medium, and small. Total yield was calculated as the sum of marketable yield and culls.

Statistical analysis. All data was analyzed using linear mixed techniques implemented in SAS PROC GLIMMIX (SAS/STAT 14.2; SAS Institute Inc., Cary, NC). Soil physical parameters within each soil depth and weed population each day after transplanting were analyzed using land use treatment as a fixed effect. Block was considered a random effect. When the F value of the ANOVA was significant, least-square mean comparisons using the Tukey adjust were

performed at a P value of 0.05. Soil compaction grid data was georeferenced within each plot and heat maps were created using the Surfer v. 16 Software (Golden Software LCC, Golden, CO).

Results

Weather Conditions. Weather conditions of daily rainfall and maximum, minimum, and average air temperature during the experimental period are presented in Figure 3. Rainfall events accumulated 339 mm and were well distributed during the tomato growing season. Daily maximum air temperature was between 26.7°C and 37.8°C; while the daily minimum air temperature for the growing season fluctuated between 10°C and 23.9°C. Daily average air temperature for the growing season was between 18.3°C and 29.4°C.
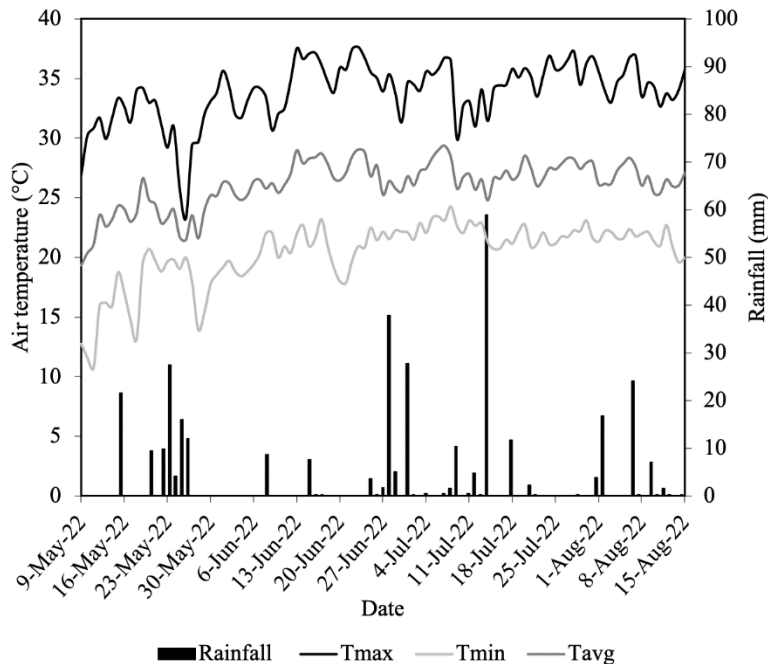

Figure 3. Weather Conditions for Tomato Growing Season. Daily maximum, minimum, and average temperature and rainfall events during the tomato growing season.

Weeds. Morning glory (*Ipomoea purpurea*), ground cherry (*Physalis pruinosa*), pig weed (*Amaranthus blitoides*), nut sedge (Cyperus rotundus), and grasses [Bahia Grass (*Paspalum notatum),* Johnson Grass (*Sorghum halepense*), and Bermuda Grass (*Cynodon dactylon*)] comprised the majority of weeds among treatments. The main effect of land use treatment and sampling time, expressed in DAT, was significant on these populations (Table 7).

Table 7. Main effect of land use treatment and days after tomato transplanting (DAT) on the number of morning glory, ground cherry, pig weed, nut sedge, grasses, and total number of weeds.

Effect	Morning glory		Ground Cherry		Pig weed		Nut sedge		Grasses		Total weeds	
Treatment												
Fallow	2.3	a[z]	5.5	a	2.1	a	6.9	a	17.0	a	33.8	a
Sorghum	0.7	b	8.8	a	0.9	ab	2.7	b	3.2	b	15.3	b
Tillage	0.6	b	4.6	a	0.5	b	1.8	b	1.6	b	10.0	bc
Tomato	0.4	b	0.9	b	0.1	b	1.2	b	0.0	b	2.6	c
p-value	***		***		*		***		*		**	
DAT												
28	0.1	b	4.3	b	0.6	ab	4.3	a	14.0	a	23.3	a
45	1.2	ab	10.3	a	0.5	ab	2.3	ab	4.4	b	18.6	ab
52	2.0	a	3.6	b	1.4	ab	4.8	a	1.9	c	13.8	b
60	0.8	ab	4.6	b	1.9	a	1.6	b	5.9	b	14.8	b
76	0.8	ab	1.9	b	0.0	b	2.6	ab	1.1	c	6.4	c
p-value	*		***		*		ns[y]		*		*	

[z] Values followed by the same lowercase letter indicates no significant differences ($P < 0.05$) among treatment or DAT according to Tukey test.
[y] ns = not significant; * means $p < 0.05$; ** means $p < 0.01$; *** means $p < 0.001$.

In general, the fallow ground treatment had significantly higher total number of weeds than tillage and sorghum. The lowest total number of weeds was measured for the tomato treatment. The first week of observation had significantly more weeds than any of the other

weeks of observation, while the final week of observation (6.4) had significantly fewer weeds than any of the other weeks of observation.

Grasses dominated the fallow treatment, while pig weed was the least abundant. For Sorghum, morning glories were the least common weed and ground cherry was the most common weed. Ground cherry was the most abundant weed grown in the tillage treatment, while pig weed was the least abundant weed. The most common weed grown in the tomato treatment was nut sedge, and grasses were the least common weed.

Soil physical parameters: The main effect of land use treatments had a significant impact on soil compaction (Figure 4), which was similar across the entire area within each treatment (Figure 5). Soil compaction was the highest for the fallow ground treatment followed by tillage, cover crop, and tomato treatments. Particularly, soil compaction averaged 3583 kPa for fallow ground, 2853 kPa for tillage, 1933 kPa for sorghum, and 1181 kPa for tomato.
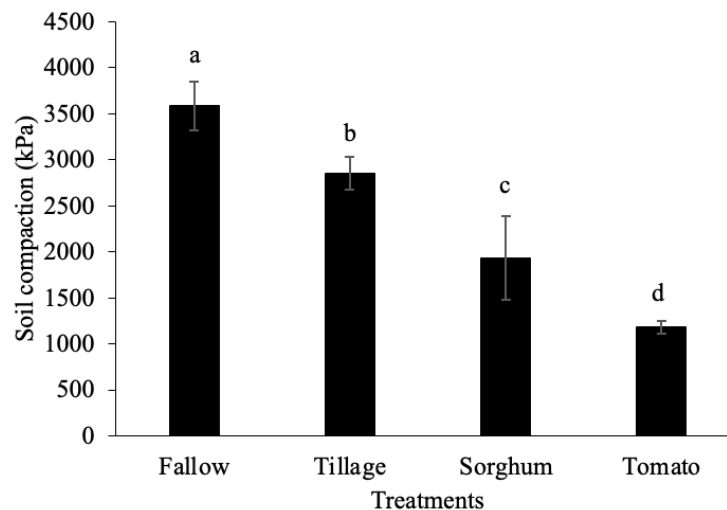

Figure 4. Effect of fallow, tillage, sorghum, and tomato treatments on soil compaction. Bars represent the standard deviation. Note: Values followed by the same lowercase letter indicates no significant differences (P < 0.05) among treatment according to Tukey test.
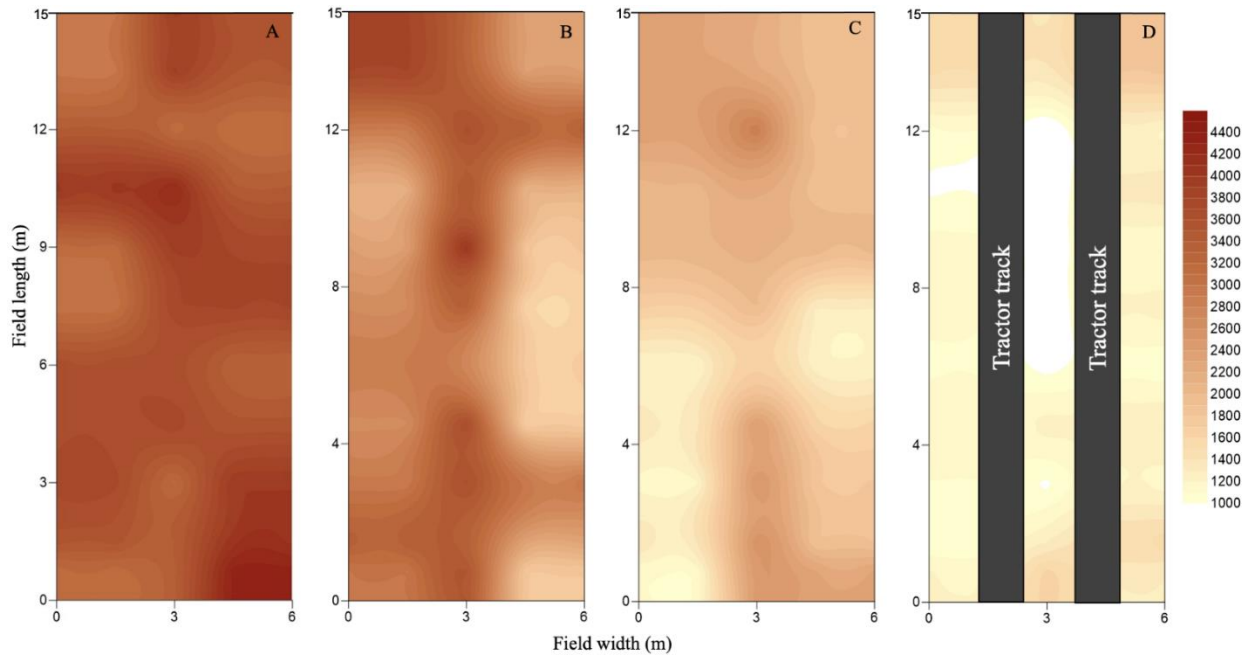
46

Figure 5. Main effect fallow ground (A), tillage (B), cover crop (C), and tomato (D) treatments

on soil compaction in the top 30 cm of soil.

Soil Bd, SAT, FC, PWP, and AW at soil depths of 15 cm and 30 cm are presented in Table 8. However, land use treatments had no significant effects in these soil physical parameters, except by soil FC and AW at 15 cm soil depth.

Table 8. Main effect of treatments on soil bulk density (Bd), saturation (SAT), field capacity (FC), permanent wilting point (PWP), and available water (AW) at 15 and 30 cm soil depth.

Treatments	Bd	SAT	FC	PWP	AW
	$g\ cm^{-3}$		$cm^{3}\ cm^{-3}$		
			15 cm		
Fallow	1.47	0.31	0.22 c[z]	0.06	0.16 b
Tillage	1.46	0.33	0.26 ab	0.07	0.18 ab
Sorghum	1.41	0.36	0.28 a	0.06	0.22 a
Tomato	1.49	0.33	0.24 bc	0.06	0.18 ab
p-value	ns[y]	ns	**	ns	*
			30 cm		
Fallow	1.58	0.33	0.26	0.09	0.17
Tillage	1.66	0.35	0.25	0.08	0.17
Sorghum	1.55	0.37	0.24	0.09	0.15
Tomato	1.64	0.33	0.23	0.08	0.15
p-value	ns	ns	ns	ns	ns

[z] Values followed by the same lowercase letter indicates no significant differences ($P < 0.05$) among treatment according to Tukey test.
[y] ns = not significant; * means $p < 0.05$; ** means $p < 0.01$; *** means $p < 0.001$.

Soil Bd averaged 1.45 g cm^{-3} at 15 cm and 1.60 g cm^{-3} at 30 cm among all land use treatments. Soil SAT averaged 0.33 m^3 m^{-3} and 0.34 m^3 m^{-3} at 15 cm and 30 cm soil depth among all treatments, respectively. Soil FC at 15 cm of soil was significantly the highest for the cover crop treatment (0.28 m^3 m^{-3}) followed by tillage (0.26 m^3 m^{-3}), tomato (0.24 m^3 m^{-3}), and the lowest for the fallow treatment (0.22 m^3 m^{-3}). Soil FC at 30 cm soil depth averaged 0.24 m^3 m^{-3} among all treatments. Soil PWP averaged 0.06 m^3 m^{-3} and 0.08 m^3 m^{-3} at 15 cm and 30 cm soil depth among all land use treatments. Ultimately, soil AW at 15 cm soil depth was significantly the highest for the cover crop treatment (0.22 m^3 m^{-3}) followed by tillage (0.18 m^3 m^{-3}) and tomato (0.18 m^3 m^{-3}), and the lowest for the fallow treatment (0.16 m^3 m^{-3}). Soil AW at 30 cm soil depth averaged 0.16 m^3 m^{-3} among all land use treatments.

Tomato performance. During crop development, tomato plants and fruit were mostly affected by the tomato hornworms (*Manduca spp.*), armyworms (*Spodoptera spp.*), and leaf-footed bugs (*Leptoglossus phyllopus*). Total yield averaged 26,243 kg ha^{-1}, in which 21,057 kg ha^{-1} were considered marketable fruit and 5,186 kg ha^{-1} were considered culls. Grade size distribution of marketable fruit averaged 2,403 kg ha^{-1} for small tomatoes, 3,407 kg ha^{-1} for medium tomatoes, 5,656 kg ha^{-1} for large tomatoes, and 9,592 kg ha^{-1} for extra-large tomatoes.

Discussion

Weather conditions had no impact on land use treatments. Daily air temperatures were considered optimum for tomato development, which ranged between 20°C and 30°C (Zhang and Schmieder, 2019; Rylski and Spigelman, 1984); while irrigation events supplied the tomato water requirement.

Hornworm, armyworm, and leaf footed bug are common tomato pests in the southeastern U.S. Hornworm has been reported to reduce tomato yield by up to 16% (Smith and Schneider, 2004), armyworm has been reported to reduce tomato yield by up to 22% (Musser et al., 2016), while lead footed bug can reduce tomato yield up to 22% (Hare and Frank, 2003). In the present study, tomato plants were treated with two *Bacillus Thuringiensis* insecticides; however, hornworm, armyworm, and leaf footed bug were still weekly scouted and might have impacted tomato yield, which was lower than that reported for the region, which averaged 47,636.2 kg ha^{-1} in conventional production systems (da Silva, 2019). Tomato yields might have also been impacted by the slow release of nutrients in organic fertilizers compared to synthetic fertilizers, which reduces soil nutrient availability during growing (Bergstrand et al., 2020; Pavlou et al., 2007). In general, marketable yields lower than 42,032 kg ha^{-1} are considered non-profitable for growers in conventional production systems, given a tomato box (28.02 kg ha^{-1}) is sold at $10.00

(Fonsah et al., 2022). However, organic tomatoes have a premium value, and economic analysis is still required to ensure the yield of 21,057 kg ha^{-1} is profitable.

Regarding the effect of land use treatments on weed population, fallow ground had the highest total number of weeds. Fallow ground has previously been reported to be a strategy to manage weed seed banks, if weeds are controlled prior to flowering (Teasdale, 1996; Delate and Cambardella, 2004). In the present study, there was no control of weeds on the fallow ground treatment; therefore, given the short life cycle of weeds and optimum environmental conditions of the region for weed development (Fryer and Chancellor, 1970; Anderson and Richardson, 1982), fallow ground is not recommended for organic transiting fields.

The process of tillage involves disturbing the surface of the soil, uprooting and burying weed seeds, and disrupting the weed's root systems (Mohler and Johnson, 2009). Although tillage is effective in immediately controlling weeds, it can also disturb dormant weed seeds from deeper layers in the soil, potentially causing a resurgence in weed populations (Cardina et al., 2002). Therefore, despite weed numbers being lower than those in fallow fields, it is possible that the tillage depth was excessive, bringing some weed seeds closer to the surface where they could germinate and grow.

Sorghum is a well-known weed suppressor and is commonly used in the southeastern U.S. (Sodré et al., 2014; Bishnoi et al, 1990). In the present study, the dense canopy of sorghum effectively shaded the soil surface, reducing light penetration and inhibiting weed growth (Teasdale and Abdul-Baki, 1998). Sorghum also has allelopathic properties, which may have helped to inhibit the growth of weeds (Duke and Dayan, 2011). Consequently, growing sorghum as a cover crop in the first year of organic transition can help growers to minimize the weed population during the summer and might be an option for growers in areas under severe weed

pressure where the chances of failure planting a cash crop is high. It is important to highlight that

selecting the appropriate cover crop will depend on several factors, such as growing season, crop

rotation, weather conditions, and soil types (Teasdale and Abdul-Baki, 1998; Snapp et al., 2005).

Sorghum was shown to be a good option under the conditions of the present study.

The weed population was the lowest for the tomato treatment, particularly, due to the

raised tomato beds, which were laid on with a completely impermeable plastic mulch. Plastic

mulching is a common crop management practice used for vegetable production in the

southeastern U.S., which effectively control weeds, improved soil moisture and temperature, and

increased soil microbial biomass and enzyme activity (Lamont, 2017; Maughan and Drost,

2016). Consequently, plastic mulching promotes tomato growth, development, and yield

(Mendonça et al., 2021). Growers planting tomatoes in the first year of organic transition should

use plastic mulching as a strategy to suppress weeds.

Regarding the effect of land use treatments on soil physical parameters, soil compaction

was evaluated in the top 30 cm of soil, while soil Bd and soil water parameters (i.e., PWP, FC,

SAT, and AW) were evaluated at 15 cm and 30 cm soil depth. In general, changes in soil

physical parameters may take up to three years depending on crop management practices

(Steward et al., 2018). Fallow ground treatment had no impact on any soil physical parameter,

while tillage had minimal impact only in the soil compaction. Contrarily, the cover crop

treatment planted with sorghum and the tomato treatment improved soil compaction, FC, and

AW. The use of sorghum as a cover crop to reduce soil compaction and improve water holding

capacity has been previously reported (Calonego et al., 2017; Olibone et al., 2010). Contrarily,

the use of plastic mulching in vegetable production, including tomato, tends to increase soil

compaction and reduce water availability (Lalitha et al., 2010), which disagrees with the findings

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of the present study. Particularly, frequent irrigation events in our plots probably increased soil porosity and reduced soil compaction in the tomato treatment (Soleymani and Nazemi, 2015), misleading the soil compaction data that may not represent the impact of this treatment. Therefore, an increase in soil compaction results in reduced root growth, and poor biomass accumulation; consequently, decreased fruit yield and quality of cash crops (Kuhlman et al., 2012). Growing sorghum in the first year of organic transition in areas where soil water holding capacity is poor can be a strategy to improve soil health parameters for future cash crops, while reducing the likelihood of failure.

Overall, the main effect of land use treatments indicated that growing tomatoes, planting sorghum, and tillage can suppress the weed population compared to fallow ground. Soil physical parameters had minimal to no impact from land use treatments. Results indicated that growing sorghum might be the best strategy in the first year of organic transition in the environmental conditions of our study; however, an economic analysis on the yield of tomatoes is still required to ensure growers' success in the case of tomatoes being grown in the first year of transitioning.

Chapter 4

Conclusion

Lettuce production success is highly attributed to ideal weather conditions such as rainfall and temperature as well as adequate nutrient availability. Additionally, cultivar selection must be taken into consideration when establishing growing systems as each growing system provides different conditions that may only suit select lettuce cultivars. Ideal temperatures for lettuce growth range from 16°C to 25°C with damage occurring above 29°C. Consequently, farmers in regions with daily maximum averages that exceed this ideal range could benefit from one of the more climate controlled growing systems: high tunnel or hydroponics. Alternatively, organic operations could provide greater economic gain for farmers who can provide ideal nutrient levels without the need for the addition of intense application.

Our study revealed that 'Truchas' had no significant difference from 'Monte Carlo' and 'Breen' in head weight within the organic system and should be considered adapted to an organic system. Cultivars 'Bluerock', 'Breen', 'Coastal Star', 'Milagro', 'Newham', and 'Panisse' had the highest head weight within the high tunnel system and should be considered well adapted to this growing system. Cultivars 'Grazion', 'Panisse', 'Salanova Green Butter', and 'Bauer' had the highest head weight in the hydroponics treatment and could be considered cultivars that are well adapted to growth in a hydroponics system.

Transitioning to organic production can be challenging, especially for small scale operations. Our study aimed to develop an economic and labor effective method to transition to organic production. The results of our study revealed that growing sorghum as a cover crop is a sound strategy to transition to organic production due to the benefits of weed suppression, reduction in soil compaction, and ease of management. Alternatively, tomato production has

potential to be a useful option to transition to organic production with the same benefits of weed suppression and the added benefit of potential economic gain from tomato yield, however analysis of economic gain is required to determine if this transition treatment is viable. Tillage and fallow are not considered productive options for transitioning to organic as weed suppression was minimal and soil parameters were not improved or significantly different from that of sorghum and tomato production.

Chapter 5

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