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# Observing Changes in Vegetable Production through Alternative Agricultural Practices

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# OBSERVING CHANGES IN VEGETABLE PRODUCTION THROUGH ALTERNATIVE AGRICULTURAL PRACTICES

A Master's Thesis

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Master of Science, Plant Science

By

Austin Grey Livingston

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**OBSERVING CHANGES IN VEGETABLE PRODUCTION THROUGH**

**ALTERNATIVE AGRICULTURAL PRACTICES**

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**ABSTRACT**

Locally, responsibly grown produce is becoming more popular as consumers are shifting to organic products or those obtained at a local farmer's market. The importance of soil health through conservation practices is increasing as the negative effects of industrial production are apparent. The over-application of synthetic fertilizers, soil erosion from wind and water, and nutrient leaching in high vegetable production areas has initiated a need for the investigation of alternative management practices. The main objective of this study is to evaluate the effects of tillage and cover crops in the production of green beans and okra. In 2019 and 2020, Blue Lake green beans and Clemson Spineless okra were planted at the Missouri State University Darr Agricultural Center. Tillage and no-till treatments were applied for the 2019 growing season, and cover crop treatments were implemented in November of 2019 for the 2020 growing season. Vegetable harvests were conducted throughout both growing seasons to determine calcium (Ca), phosphorus (P), magnesium (Mg), and potassium (K) concentrations in produce as well as yield. Soil nutrient content was determined from soil samples collected after the 2020 growing season. Green beans showed a statistically significant increase in tillage plots for growth rate in both seasons as well as yield in 2020. No significance was found in okra through any treatment method. These findings suggest that tillage increases short-term green bean production in regards to yield, but does not affect the productivity of okra.

**KEYWORDS**: cover crops, vegetable production, no-till, tillage, nutrient density, green beans, okra

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# INTRODUCTION

In the recent years, an apparent market shift towards local, organic, responsibly grown, or a combination of both can be recognized. Consumers are becoming more educated and aware of the commercialized food system and many are choosing to spend their food dollars in support of a more sustainable or responsibly grown agriculture production system. Consumers are able to do this by purchasing meats, fruits, and vegetables from local farmer's markets, roadside stands, or choosing a USDA certified organic product in grocery stores. According to an article published in 2007 by the Nutrition Business Journal, organic products averaged a sales growth rate of 17% ranging from 1998 until 2006 (Nutrition Business Journal, 2007). Continuing increases of organic food sales have been observed, but with a less drastic growth rate. What is driving this shift in food dollars and increase in a more "sustainable" agriculture model? For the general population, the perception of organic agriculture products may be associated with the lack of synthetic materials used in production. Synthetic agriculture products may include insecticides, herbicides, pesticides, or fertilizers (Worthington, 2001). Since certified organic farms abstain from the use of synthetic materials for weed and pest management, tillage becomes one of the primary practices enacted on cropland. With the known destructive impacts on soil health caused by tillage, relying solely on organic vegetable production may not be the silver bullet of sustainability.

## Unsustainability of Current Agriculture Management Practices

Worldwide agriculture operations ranging from commercial crop production, rangeland and industrial livestock operations, as well as deforestation for agricultural purposes account for

almost 40% of worldwide habitable land. When deforestation and land use conversion in general occurs from a natural state to a managed state, the impacts can be harmful or detrimental to native vegetation as well as native animals (Badgley, 2019). We are changing the landscape from a highly functioning ecosystem, such as a diverse woodland or a native prairie, and replacing it with a highly industrialized model of agriculture that goes against nature instead of working with nature. Whether in vegetable production, crop or grain production, forest products, or livestock production, the producer has taken the genetic diversity, species diversity, and habitat diversity, and made them obsolete (Badgley, 2019). Monoculture crops have dominated commercial agriculture systems which are seen in multiple acres of one crop of the same species, identical genetic diversity to perform a desired task, such as yield or maturation date, and are grown in like habitats under cultivation. With the lack of natural diversity being present in our current agriculture model, it is no surprise that producers have become reliant on synthetic materials in order to support these management practices.

In a 2017 study conducted by Eric Brennan on the sustainability of vegetable production in the Salinas Valley district of California, Brennan states problems that are occurring in that region due to conventional management practices. The main consequences the Salinas Valley are facing primarily pertain to losses. Losses of soil from water and wind erosion, nutrient loss due to water erosion, nutrient leaching due to monoculture crops and over-application of fertilizers, and the accumulation of nitrates as a result of synthetic fertilizers (Brennan, 2017). Land under cultivation for vegetable production is only a fraction of what is used for commercial grain agriculture. Due to the substantially less land area and the nature of most vegetable crops, the management level is much more intense and if possible, producers will most likely attempt at least two crop rotations in one growing season. This intensity drives and pressures most farmers

to rely on conventional agriculture practices such as tillage, fertilizers, and pesticides (Hoyt et al., 1994).

Unfortunately, signs of unsustainable agriculture practices on both commercial agriculture and vegetable production are not limited to the United States, but rather a problem faced around the world. Ted Lefroy, a professor at the University of Tasmania in Australia organized a conference that addressed the need for an agriculture model that more closely mimicked natural ecosystems. A report on the event clearly stated that the need for the conference was due to, "the unsustainability of agriculture as currently practiced around the world. . ." (Hatton & Williams, 1997). A research study conducted in Turkey attempted to find alternatives to herbicides for weed control in vegetable production. This shift in focus on the reduction or elimination of chemicals is due to the awareness of the potential toxicity and misuse of herbicides. Misuse of herbicides in vegetable production creates apprehensions regarding residual herbicide presence on consumables as well as the potential for the development of herbicide-resistance weeds (Jabran & Chauhan, 2018; Mennan et al., 2020).

India is another country that is recognizing similar challenges caused by unsustainable agricultural practices. The problems in India, and those that are found around the world in all conventional food production systems, stem from the increase in need for inputs. As stated before, agricultural inputs can be products like synthetic fertilizers, chemical herbicides and pesticides, time and fuel cost for the application of materials, as well as supplemental irrigation. Every input results in a direct cost for the producer in regards to time and production expenses, and indirect costs of degrading soil and water resources as well as negatively effecting the environment for the community (Ranjan et al., 2017). Finally, back in the United States, it has been decades since researchers have determined that the reliance on a single method of pest

control (weeds, fungi, bacteria, or insects), is not sustainable and has the potential to create detrimental populations of resistant individuals to that control method. In vegetable production, cultivation of weeds has been more difficult due to the slower availability of genetically modified herbicide resistant varieties, which made demand for human labor expensive. Herbicides gained popularity in vegetable production due to the expense of labor that could possibly be unavailable (Putnam, 1990). Throughout the realm of varying agriculture commodities, a recognizable trend in the unsustainable qualities of the current commercial production models is recognized globally across varying decades.

**Declination of Nutrient Concentrations and Impacts on Human Health**

With the evidence shown for an unsustainable agriculture model, a final consequence is apparent with the possibility of outweighing previous examples in terms of severity; human health. People need food to survive. Not only the substance of food, but foods that contain adequate levels of energy, nutrients, vitamins, and minerals. Unfortunately, the drive to commercialize agriculture with the primary emphasis on yield has resulted in the declination of nutrient and mineral content in fruits, vegetables, and grains. Producing and marketing agriculture products with inferior levels of essential nutrients results in the declination of the health of local and global communities. This unintentionally is another part of the undesirable "cycle" of production agriculture. To explain, the decline in nutrients in our produce creates a revolving door, or cycle, that fuels the perceived need of a yield-focused system. As a result of a diluted concentration of nutrients in vegetables caused by poor management, consumers need to purchase a larger quantity of product to obtain adequate levels of vitamins and minerals. Consumers purchasing larger quantities of unsustainable products create a larger demand and

eventually returns to the commercialized producer as pressure to supply larger quantities of their product, therefore continuing the cycle of unsustainability.

An in-depth study conducted in 2001 by Virginia Worthington sought to quantify the nutrient content in conventional versus organic agriculture practices. Crops of interest were lettuce, cabbage, carrot, spinach, and potato. The general conclusion of this study found that nutritionally beneficial nutrients and minerals were more abundant in organic crops when compared to conventional crops. In contrast, levels of heavy metals were shown in fewer quantities in organic vegetables (Worthington, 2001). The results of this study clearly show the nutritional benefits of an agriculture production system that relies on a more sustainable approach.

A concept that well describes the correlation between yield and concentration of nutrients is referred to as the dilution effect. In 2009, a research article written by Donald Davis used this term heavily, but explained that this concept was generally accepted as common knowledge. The dilution effect is simply defined as an increase in yield will generally result in lower concentrations of nutrients, vitamins, and minerals. This is a clear representation of the inverse relationship the two variables contain. Tying this concept back to previous discussion of increase in pressure to commercialize fruit and vegetable production, the dilution effect provides a well-defined explanation of the shown decrease in nutrients. Davis lists the commonly researched fruits and vegetables, which are unsurprisingly some of the most profitable, which include berries, tomatoes, potatoes, peppers, and onions. He also states that in studies within the past 50–70 years, vegetables have shown a decline in nutrient, vitamin, or mineral concentrations ranging from 5–40% (Davis, 2009). Through data review from the U.S. Department of Agriculture (USDA), Davis found that vegetables were more susceptible than fruits to show the

dilution effect caused by a larger increase in yield when compared to fruits and noted that the apparent goal of vegetable breeders is to increase production through higher-yielding varieties (Davis, 2009). The declination of essential nutrients that are found in current commercialized production systems has the greatest impact regarding its effect on human health.

There are also apparent detriments to human health that may be considered indirect sources. Soil erosion, nutrient runoff, nitrate accumulation in the soil, and nutrient leaching can all negatively affect human health. Reaching back into the article highlighting vegetable production in California's Salinas Valley, groundwater pollution is a large concern for the community. Since the Salinas Valley has been an intensively managed region for vegetable production for decades, the reliance on synthetic fertilizers has contributed to amounts of nitrates that have leached and contaminated groundwater in that region (Harter et al., 2012). The conventional vegetable production system is also associated with nutrient leaching in the soil profile that can cause groundwater contamination as well as the susceptibility for nutrient runoff. Another article previously referenced from India recognizes the same problems in their local communities. It states that since Indian agriculture is also dominated by a commercialized model, the authors recognize that the dependence on fertilizers, pesticides, and herbicides are contributing to the degradation of local soil and water bodies (Ranjan et al., 2017). Just like the unsustainability of agriculture is recognized all over the world, similar problems and hazards can be seen as a direct and indirect cause of this type of agricultural management system.

It is commonly known that the majority of farmers belong to a multi-generation operation. A smaller percentage of farmers are first-generation farmers due to the potential lack of exposure to agriculture, expensive land cost, or high input costs to start an operation. This creates a mentality that is resistant or hesitant to try new things. Younger farmers may be

prideful of the fact that they inherited the operation from their parents, and their parents inherited it from their grandparents, etc., cementing a tradition of how the operation is conducted. Simply, if a farmer's parents, grandparents, and other generations have tilled the same soil and planted the same crops throughout decades, it would be expected to face resistance when offering ideas of change. Brennan hypothesized that an increase in reports and research showing the benefits of cover crops and soil health in vegetable production would help persuade producers to adopt new management practices on their operations (Brennan, 2017). The increase in awareness of the benefits of a soil-focused observation is promising as more and more producers adopt alternative practices, but how much more research will it take to reach all producers across all crop types?

**Alternative Practices to Mitigate Agriculture Unsustainability**

I have shown many problems associated with commercialized practices for vegetable production, but are there other benefits from adapting a new system other than to mitigate the harmfulness of our industrialized agriculture? I stated above the fact that the organic food market has steadily grown within the past two decades. It is common knowledge that prices for organic products can range from slightly to greatly higher than conventional products. An article published in 2010 highlights the fact that not only are organic vegetables rising in popularity, but fresh produce in general has shown an increase in demand (Dettmann & Dimitri, 2010). As a commercialized producer facing problems from impacts previously stated, the choice to adapt new management techniques could be enticing. If organic products receive a higher price point through marketing, an increase in gross income could be seen. Organic products refrain from using costly synthetic inputs which would allow for a decrease in input costs. An increased

gross income combined with decrease production costs would allow for a potentially greater net income for the operation.

If the conventional model of agriculture is continuously degrading our natural environment and negatively affecting our communities, alternative means of vegetable production need to be highlighted. I tend to think of agricultural management models as options for increasing complexity in the system with conventional tillage being the lowest and polyculture cash crops followed by a multi-species cover crop as the highest. There are many "rungs on the ladder" between those two options, so I will describe different management techniques varying in complexity. To begin, a reduction in tillage operations would be the most attainable change for a producer. A 1994 study reviewed the possibilities of alternative tillage options for commercial vegetable production. Since most small-seeded vegetables are transplanted to the field as opposed to direct seed operations, conventional transplanters are commonly used equipment. A method of strip tillage is recommended for the ease of use and would not require the purchase of new equipment or the alteration of owned equipment. Instead of using tillage tools to plow or disk an entire field where 100% of the soil is altered, strip tillage reduces the amount of soil disturbed by only tilling individual strips that will contain a row of vegetables. However, while this system reduces the percent of land that is disturbed, a reliance on synthetic herbicides may be necessary to control undesired vegetation between rows (Hoyt et al., 1994; Wallace & Bellinder, 1992).

## Cover Crops

Cover crops can be a beneficial and profitable tool if they are utilized effectively and properly. A study conducted in 2017 sought to identify benefits to soil health caused by the use

of cover crops in vegetable production. The results showed that even though mechanical tillage was used to incorporate cover crop biomass into the soil, cover crops provided multiple benefits to the soil as well as being profitable for the producer. Specifically, they found that cover crops helped reduce nitrogen lost by leaching, reducing soil erosion through wind or rain, and most importantly an increase in vegetable yield (Brennan & Acosta-Martinez, 2017). Eric Brennan conducted another study regarding cover crops in vegetable production. He suggested multiple ways of incorporating cover crops into a rotation, which depended on what crop was to be grown in the following season. Suggestions included a low-residue cover for a quicker breakdown in the spring, frequent mowing of some species to mitigate runoff, and the most interesting use, creating a cover crop "juice" (Brennan, 2017). This process would take harvested cover crops, press to separate the juice from biomass, and finally apply the liquid back onto fields as a fertilizer.

**Substitutions for Tillage and Synthetic Inputs**

Alternative means of tillage or herbicide use for vegetable production has been researched throughout the world. In New Hampshire, tarps were explored as an option for terminating high-residue cover crops in order to remain an organic operation producing cabbage. Compared to other means of terminating cover crops, i.e., tillage, herbicide, mowing, or crimping, of which some depend on correct timing or else termination will be unsuccessful, tarps would allow a crop to be killed at any stage of growth (Lounsbury et al., 2018). In summary, several benefits were noted from the use of tarps such as retention of soil moisture, increased microbial populations, and an increase in yield (Lounsbury et al., 2018). Mulching was also an area of interest for water retention and production increase in vegetables in India. In this

country, over 80% of water use is tied to agriculture (Ranjan et al., 2017). The use of mulches can aid in retaining moisture and can provide an alternative to growing a cover crop for the same benefits. Organic mulch options could include grass clippings, straw, or leaves, but the highest yield benefit was noted in tomato and okra crops which utilized straw mulch (Ranjan et al., 2017).

Focusing on weed control in vegetable production, a study investigated biological control agents as an alternative to herbicide. Biological agents refer to fungi or another living organism that is selected as a predator to weeds or even insects and introduced in populations large enough to significantly impact a management issue. This biological approach is much safer than the use of synthetic materials and fungi have proven to work well in vegetable production (Putnam, 1990).

In regards to herbicide applications, a similar approach to strip tillage can be put in practice by the producer. This technique is referred to as herbicide banding. Herbicide banding can reduce the total amount of herbicide used in production and can provide a more accurate and precise delivery to undesired vegetation. Banding can be used to eliminate competition of weeds in a row prior to seeding to establish competitive advantage (Hoyt et al., 1994), or used between crop rows following emergence to control between row weeds (Wallace & Bellinder, 1992). Although herbicide and tillage management strategies enacted on vegetable cropland throughout the world can differ, all share the same goal of reducing agricultural inputs and conserving natural resources.

Global climate change is a worldwide issue that is in the forefront of many media outlets today. Many attribute the changing climate to the increase in industry throughout human history, and the increasing commercialization of agriculture has been a key driver in changes to our local

and global environment. Changes in atmospheric carbon seem to be a primary concern regarding the influences of agriculture. "Globally, the quantity of C stored in the soil is second only to that in the ocean (38,400 Gt)" (Stockmann et al., 2013). Tillage is the main agricultural practice that will release soil stored carbon back into the atmosphere. Stockman et al. (2013) summarized an analysis of the changes in soil stored carbon levels when land use is changed. The findings showed that when land was converted from a more "natural" ecosystem or a system with permanent groundcover (pastures) to an agriculture/cropping system, the levels were all in decline. On the contrary, when a cropping system was returned to a more native state, soil carbon levels increased (Guo & Gifford, 2002; Stockmann et al., 2013). This clearly shows that when humans manipulate native or natural land uses to expand or convert into agricultural land, carbon that was once stored in the soil is now filling the atmosphere. William Quarles states that "up to one-third of global greenhouse gases come from agriculture" (Quarles, 2018). Agriculture greenhouse gas emissions can be tied to releasing soil-stored carbon, farm implement emissions, livestock, or synthetic inputs. Just as agriculture has been a large portion of the cause of greenhouse gases, it can also be a large percentage of the solution. Through the process of photosynthesis, plant growth can help remove carbon dioxide from the air and put it back into the soil (Quarles, 2018). Quarles (2018) summarized a study comparing levels of carbon in organic versus conventional agriculture soils and found that organic soils were able to sequester more carbon than conventional soils (Quarles, 2018; Gattinger et al., 2012).

**A More Regenerative Agriculture**

The highest rung on the ladder of complexity for alternative agriculture methods in vegetable production would be following principles of regenerative agriculture. The system of

regenerative agriculture relies on treating the operation as an ecosystem and attempting to emulate native biological communities and combining all previous individual practices into one. Sherwood and Uphoff (2000) state that the current and historical agriculture principles were to mechanically manipulate the landscape while it should be a more focused biological approach. Synthetic materials and other agricultural inputs have been used through decades to create a desired environment when a more sustainable approach would have been to follow natural principles that would enhance the soil and product (Sherwood & Uphoff, 2000). No-till planting is one of the largest factors in regenerative agriculture. As the name implies, no-till agriculture lacks the use of conventional tillage equipment and any residue from previous crop or cover crop is left on the soil surface (Montgomery, 2007). Other systems that closely resemble and share the same goals as regenerative agriculture include agroecology and permaculture. Agroecology focuses on combining biological diversity and ecological principles into agriculture production models, while permaculture seeks to create extremely diverse ecosystems through multi-level management of trees, crops, soil, and water resources (Dahlberg, 1993). Regenerative agriculture seeks to follow principles of nature through no-till planting and the use of diverse summer and winter cover crops which both reduce the need for synthetic inputs because of the increase in soil health and increases in nutrient cycling and weed control.

**Impacts Correlated to Vegetable Production**

Since vegetable production accounts for only a fraction of agriculture land in the United States, research regarding these alternative methods can be somewhat limited compared to row crop production. Nevertheless, a transfer of knowledge can be easily applied to all cropland, regardless of species or type of crop being grown. Soil is one thing that all producers have in

common and the necessity to retain and emphasize the importance of soil health is universal. A decline in essential nutrients and minerals has been seen as a result of the industrialization of vegetable production causing the undesirable consequence of an intake of consumption in order to receive the same nutritional benefit as decades before. Showing or advocating for a “one-size-fits-all” management approach can be dangerous and rarely true, but the application of a regenerative agriculture system on all cropland will provide multiple management strategies to not only sustain the degraded soils of production agriculture, but regenerate the ecosystems above and below ground to reduce erosion and runoff, reduce costly agricultural inputs, increase yield and diversity, and increase the nutrient values of agricultural products.

The overriding vegetable production objectives for this project are to: 1) determine okra and green been success rates through nutrient analysis, yield, and growth rates in a first-year no-till system, and 2) to observe the relationship between plant health and soil health through nutrient analysis of plant and soil. Based on these areas of interest, the specific study objectives for this project are: 1) to develop field plots to compare tillage and no-till management treatments in vegetable production, 2) implement various cover crop treatments to determine a relationship between cover crops and vegetables, and 3) to collect and statistically analyze seasonal data of both plants and soil under each management system.

## MATERIALS AND METHODS

### Site Selection

The Missouri State University Darr Agricultural Center, Springfield, Missouri, was selected for this research project. The Darr Agricultural Center is on the west central area of Springfield, directly south of Sunshine street off Kansas Expressway. The site also offered ease of access for students and equipment needed to conduct this research, and a consistent soil type of the plot area (Figure 1). This soil is Newtonia silt loam, mixed, superactive, thermic Typic Paleudolls with 1–3% slopes and developed from a loess parent material over residuum weathered from cherty limestone (USDA Web Soil Survey). This soil is described as well drained with low runoff potential, over 80 inches of depth without restrictive features or bedrock, and is classified as prime farmland (USDA Web Soil Survey).


**Figure 1.** Soils map of study site with plot locations (USDA Web Soil Survey).

## Environmental Conditions

For this study area, average annual rainfall is predicted to be 41–51 inches and an average annual air temperature ranges from 47–70 ºF. Lastly, this site has a frost-free period of 183–239 days (USDA Web Soil Survey). Prior to the incorporation of this project, this site was under contiguous land use as a mixture of grasses and broadleaf plants. It could be classified as a managed field or yard under frequent mowing to a height of 4–6 inches. An additional benefit at this site is the availability of water for irrigation if needed. This site contains characteristics that would easily apply to landowners in this region if they chose to incorporate alternative management techniques on their own gardens.

## Site Preparation

On 17 May 2019, an initial burn-down herbicide application of a 2.5% glyphosate mixture (Buccaneer Plus®) was applied before planting operations and tillage treatment operations. This non-selective herbicide option allowed all existing vegetation to be controlled in each plot prior to the implementation of treatments. For plots receiving tillage treatments (Figure 2), initial tillage preparation was completed using a rotary tiller powered by a tractor. Two tillage passes were done over each plot to break up the existing sod layer and to prepare the soil for hand planting. Three cover crop treatments of no cover crop,, single species cover crop, and multi-species cover crop were randomly assigned in both tilled and no-tilled plots (Figure 2).

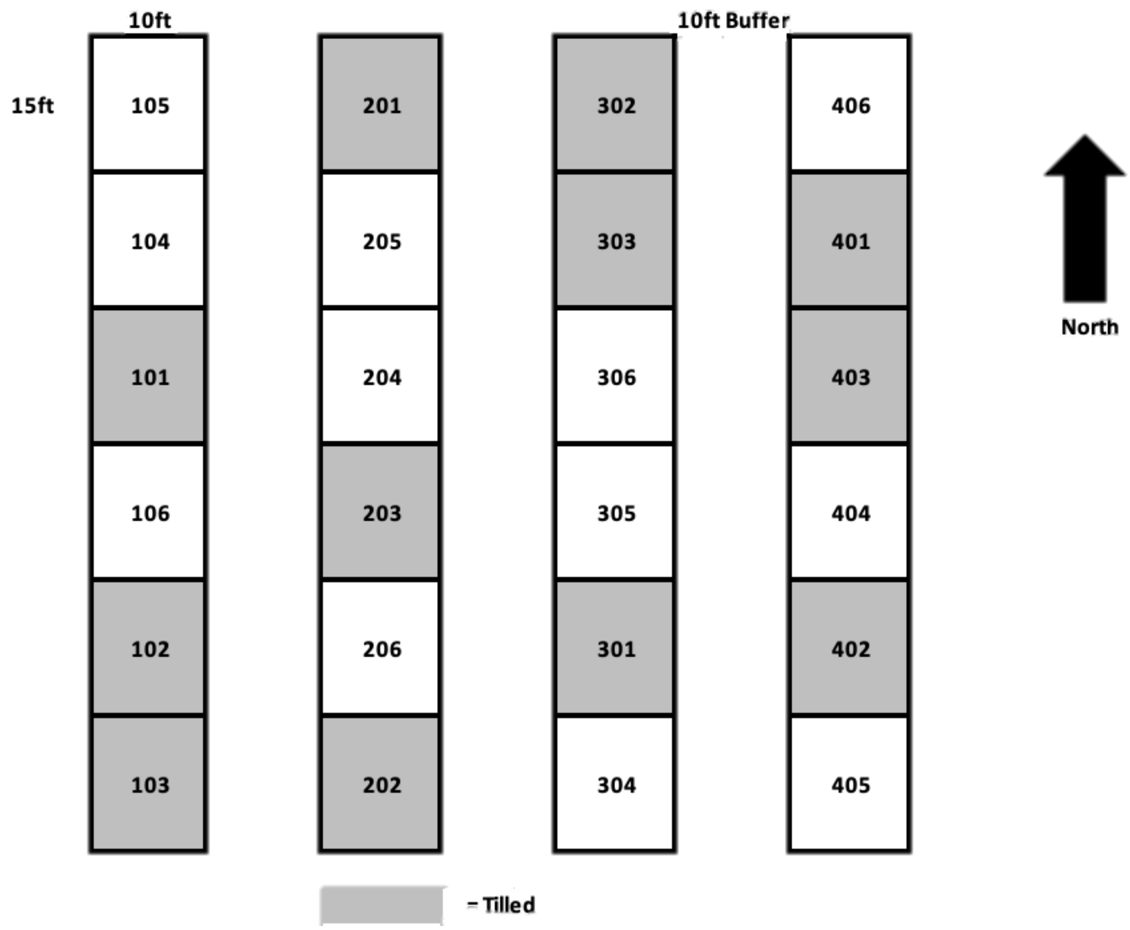


**Figure 2.** Plot map for entire two-year research study. Shaded plots received the tillage treatment, while non-shaded plots were not tilled. The final numeral in each plot indicates cover crop treatments with 1 and 4 having no cover crop, 2 and 5 having a single species cover crop, and 3 and 6 having a multi-species cover crop.

### Planting and Treatments

The project utilized a plot-treatment structure to observe changes in soil health and in vegetable nutrient quantity and yield. A randomized complete block design was used with four blocks and one plot of each treatment combination within each block. Each plot was 10 feet by 15 feet with 10-foot buffers between blocks to minimize potential effects of treatments in adjacent plots (Figure 2). Treatments were randomized among test plots in each block (strata) with each treatment being used once in each block (Larkin, 2019). Vegetable and cover crop

varieties are common and easily accessible for any backyard gardener or landowner who wants to implement a cover crop rotation (Booker, 2009).

Blue Lake Bush green beans (*Phaseolus vulgaris*) and Clemson Spineless okra (*Abelmoschus esculentus*) were planted 3 June 2019 to 7 June 2019. In 2020, all plots were planted between May 19 and May 20. Green beans were planted with a plant spacing of 6–8 inches, whereas okra was planted with an 8–10 inch plant spacing. This resulted in the establishment of about 25 green bean plants per row and 20 okra plants per row. A consistent row spacing was kept between all crop rows at approximately 19 inches to allow for weed control between crops. A consistent row spacing was kept at approximately 19 inches to allow for weed control between rows, resulting in five rows per plot with three adjacent rows delegated for green beans and two adjacent rows delegated for okra. To reduce bias between species performance, a number was randomly generated to decide if green beans or okra were to be planted on the east or west side of the plot.

Okra seed was planted one inch in depth, and green bean seed was planted 1.5 inches in depth. For tillage treatment plots, seeds were planted by hand in furrows dug by a garden hoe then covered and pressed. No-till treatment plots were planted by hand using a cordless drill with a 1-inch spade drill bit, then covered and pressed.

Cover crop treatments were planted on 13 November 2020 after all existing vegetation from the previous growing season was terminated, either from tillage treatments or from a 2.5% burndown herbicide application (Buccaneer Plus®) on 10 November 2019. Cover crops were planted by hand, broadcasting seed as evenly as possible throughout the entire plot.

**Cash Crop Species Selection**

Two vegetable species were selected for this research project: Blue Lake Bush Green Beans (*Phaseolus vulgaris*) and Clemson Spineless Okra (*Abelmoschus esculentus*). These varieties were selected because of the familiarity to gardeners across the country as well as the availability to the general public in this area. Even though specific varieties were used each year, each could be used to represent a larger group of plants, especially Blue Lake Beans. Green beans were chosen as a species of interest for this project because they are a legume, which would allow the possibility of nitrogen fixation in the summer growing season.

**Cover Crop Species Selection**

As with cash crop species, cover crop selections were carefully selected based popularity, general familiarity, and ease of availability. For this project, cover crop treatments included no cover crop, single species cover crop, and multi-species cover crop. The single species cover crop chosen was Cereal Rye (*Secale cereale*). This species was chosen because of its availability, low cost, above-ground biomass production, below ground biomass production, and for its extreme winter hardiness. The multi-species cover crop treatment consisted of Cereal Rye (*Secale cereale*), Purple Top Turnip (*Brassica rapa*), and Crimson Clover (*Trifolium incarnatum*). Purple Top Turnip was included also because of its availability and low cost, as well as the fact that it is a brassica. Having a brassica in a mix is beneficial because of the differing root system, leaf shape, and leaf heights to maximize the capture of solar energy. Finally, Crimson Clover was included for its leguminous qualities as well as for a differing root system and leaf characteristics. All species are inexpensive and available at local seed stores in bulk or by the bag and were purchased at Nixa Hardware and Seed in Nixa, Missouri.

Planting rates were determined based on the per acre recommendation for each species as well as taking into consideration site characteristics. In single-species delegated plots, Cereal Rye was planted at 150 lbs/A. Purple Top Turnips were planted at 5 lbs/A, and Crimson Clover was planted at 10 lbs/A in the multi-species plots. Cereal Rye was also planted at 150 lbs/A in the multi-species plots giving each plot a total planting rate of 165 lbs/A. Planting rates were higher than most recommendations because 1) it was desirable to have a cover crop that produced high biomass, 2) planting dates were later in the year than recommended, likely resulting in lower germination rates, and 3) each plot was small in size, so small increases in the amount of seed planted per plot resulted in a drastic increase on a lbs/A basis.

**Soil Sampling**

An initial composite soil sample of the entire study site was collected before the implementation of any treatments. The sample consisted of 25–30 soil cores that were mixed, air dried, and stored at room temperature until analyzed.

Soil samples from each plot were collected on 9 December 2020 after the completion of the growing season. Each sample consisted of 12–15 cores per plot to a depth of 6 inches (Nathan et al., 2012). Soil cores were originally split into two depths, 0–3 inches and 3–6 inches, however, were later combined into one sample per plot for analysis. All samples were air dried and stored at room temperature.

**Soil Nutrient Analysis**

Air-dried soil samples were ground in a mortar and pestle until particles could pass through a number 18 sieve.  Samples were then stored in plastic bags at room temperature until tested.

Soil pH was determined by using pHs (Nathan et al., 2012).  Ten mL of 0.01 M $CaCl_2$ was added to each 10 g (± 0.1 g) soil sample, shaken at 450 rpm (FisherBrand Multi-Platform Shaker) for 30 minutes, and recorded to the nearest hundredth using an OHAUS Starter300, model ST300 pH meter (W.W. Grainger, Inc., Lake Forest, IL, USA).

Nutrient content (% by weight) of Calcium (Ca), Magnesium (Mg), and Potassium (K), were determined using ammonium acetate extraction as outlined by Nathan et al. (2012) and Warnkce and Brown (1998) and analyzed using Atomic Absorption/Flame Emission Spectrophotometry (Agilent Technologies, 200 Series AA, Santa Clara, California, USA.) Analytical wavelengths were set at 422.7 nm for Ca, 766.5 nm for K, and 285.2 nm for Mg.

Bray I Phosphorus (P) content (Bray & Kurtz 1945) was found colorimetrically using a GENESYS 30 Visible Spectrophotometer (Thermo Scientific, Waltham, Massachusetts, USA) set at a wavelength of 660 nm.  Procedures for Bray I P (lbs/A) were outlined by Nathan et al. (2012).

**Crop Harvest**

A subsample of both okra plants and green bean plants were randomly selected using a random number generator.  Each plant was numbered and four green bean plants and four okra plants were randomly chosen to analyze all areas of interest.  Yield measurements were taken immediately after a harvest event and were expressed using the fresh weights of fruit per four

plant basis for each species. Plants were picked clean and every size fruit was added to the total yield measurement for each plot.

### Crop Average Daily Growth

Average daily growth of each variety of cash crop was taken. Each plant was measured from soil surface to the base of the highest leaf for each species with a yard stick to obtain a height measurement. Measurements were taken on 3 July 2019 and 21 July 2019. The final height measurement was then divided by the number of days from planting to estimate the average daily growth. 2020 measurements were taken on 2 June 2020 and 29 June 2020 due to an earlier planting date.

### Crop Nutrient Analysis

For all plant produce nutrient analysis tests, all vegetable pods taken from the final harvest event were placed into a forced air oven (Cascade TEK, Cornelius, OR, USA) and dried at 55°C to obtain dry material. Dried samples were then ground using a modified coffee grinder (Mr. Coffee Blade Grinder model IDS57RB). Ground plant samples were weighed to 0.25 grams (±0.005 g). Each weighed sample was digested using 5 mL of trace grade nitric acid solution (Fisher Chemical, Fair Lawn, NJ, USA) and ran through a MARS 6 Microwave (CEM Corp., Mathews, North Carolina, USA) using the MARS 6 Plant Tissue method. This method involves a 20-minute period of temperature increase to a final temperature of 200°C and is then held for 10 minutes. After sample cooling and ventilation, each sample was filtered through Q8 coarse fast flowing filter paper (ThermoFisher Scientific, Waltham, Massachusetts, USA) into a

50 mL polypropylene tube. Samples were lastly diluted using DI $H_2O$ (Barnstead E-Pure Model D4641, Thermo Scientific, Waltham, Massachusetts, USA) to achieve a final volume of 25 mL.

Calcium (Ca), magnesium (Mg), and potassium (K) concentrations of the digests were found by using Atomic Absoption/Flame Emission Spectrophotometry (Agilent Technologies, 200 Series AA, Santa Clara, California, USA.) Analytical wavelengths were set to 422.7 nm for Ca, 766.5 nm for K, and 285.2 for Mg. Plant samples were diluted 1:20 using 0.105% lanthanum oxide solution (La). Standards for plant samples were 1.00, 2.00, 3.00, and 4.00 ppm for Ca, 0.25, 0.50, 1.00, 1.50, and 2.00 ppm for Mg, and 0.25, 0.50, 1.00, and 2.00 ppm for K. Digest nutrient concentrations were used to determine percent by weight of each macronutrient in plant tissue.

Phosphorus (P) concentrations were found colorimetrically (Murphy & Riley, 1962) using a GENESYS 30 Visible Spectrophotometer (Thermo Scientific, Waltham, Massachusetts, USA). The absorption wavelength was set to 660 nm. Plant tissue digests were diluted 1:20 with DI $H_2O$. An ascorbic acid working solution (4 mL) was then added to the diluted samples and vortexed. A standard absorbance curve was set using 0.00, 0.50, 1.00, 2.50, and 5.00 ppm P in DI $H_2O$. Nutrient concentrations were expressed as percent by weight (Murphy & Riley, 1962).

## Weather Data

Weather data was obtained from the NOAA Springfield-Branson National Airport Weather Station. Average monthly temperatures and monthly precipitation were taken from May through September to compare summer growing seasons between 2019, 2020, and the NOAA 30-year average.

## Statistical Analysis

As stated above, this experiment was established as a randomized complete block design analyzed as a mixed effects model using MiniTab 19.1 (Minitab Inc, State College, PA, USA). This model was used to test for statistical significance of tillage and cover crop treatments as well as all interactions for each species. Species, tillage treatments, and cover crop treatments were considered fixed factors, and block was a considered a random factor. All interactions were considered significant when means differed at $P<0.05$. When F test showed significance ($P<0.05$), means were separated using Fisher's protected LSD ($\alpha = 0.05$). Experimental years were presented separately due to significant interactions with fixed effect factors.

## Study Limitations

Since this research study was limited to two growing seasons, more data could have been collected to observe additional changes over a longer time period. Ideally, this study would continue for multiple years for each treatment to reach its potential. Similarly to time, more cash crops should be investigated to see which treatments could maximize production. Cover crop mixes could be researched for species in an attempt to find the most suitable mix for each vegetable species. It is impossible to control the weather in a field study, so differences in growing seasons in regards to precipitation amounts and temperatures are the largest limiting factors. This study focused on a limited amount of macronutrients, so expanding the research to encompass all macro and micronutrients would be beneficial. Additional data such as infiltration rates, microbiology investigations, soil temperature, earthworm density counts, and Slake testing would be useful in determining optimum agricultural practices for vegetable production.

# RESULTS

## Weather Data

Precipitation totals for the 2019 growing season (May through September) were above the 30-year average by 29%. Rainfall in May accounted for 47% of the total growing season precipitation in 2019 (14.37 inches). Total precipitation in the 2020 growing season were 5% below the 30-year average. May also accounted for the largest percentage of growing season precipitation for 2020 having 54% of the total rainfall (11.31 inches). May precipitation was above the average in both 2019 and 2020 growing seasons, showing 65% and 55% increases above the average respectively. 2020 precipitation was below average June through September, while 2019 precipitation levels were only below average in July and September (Figure 3).

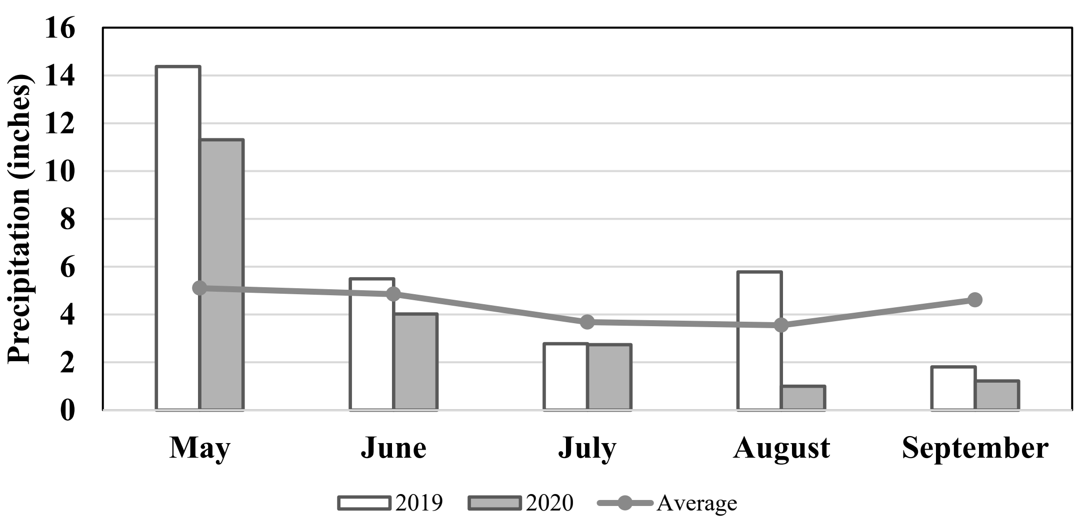


**Figure 3.** Monthly precipitation (inches) in months May through September (NOAA).

Monthly average air temperatures stayed very close to the 30-year averages (Figure 4). In 2019, May and September were the only months that were above the average temperature, by

1.1% and 12.3%, respectively.  June, July, and August months showed below average temperatures with 0.8%, 0.7%, and 0.9% lower values.

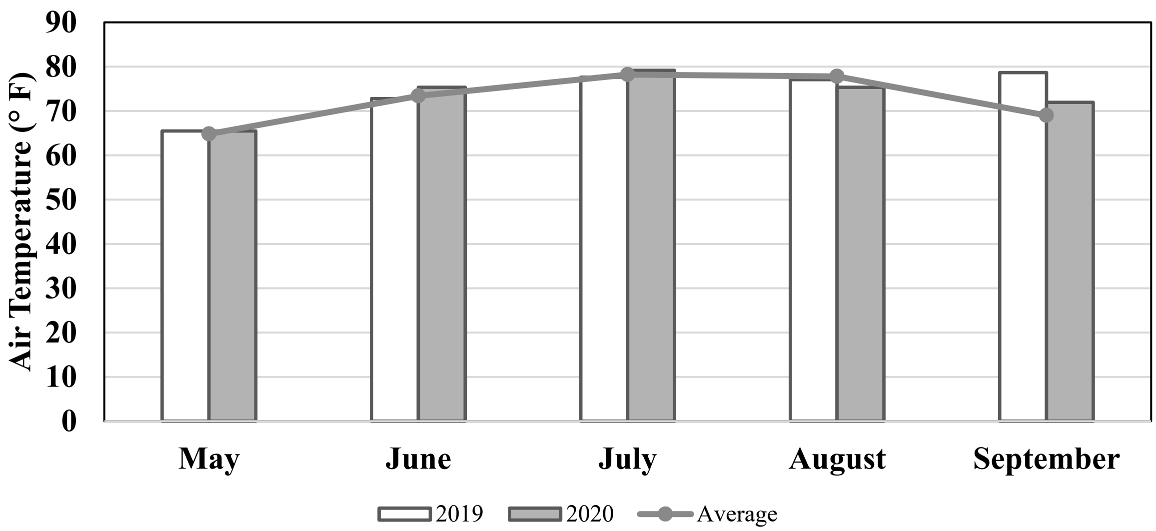


**Figure 4.** Monthly average air temperature in months May through September (NOAA)

**Plant Yields**

In 2019, green bean and okra yields between all treatments showed no statistical significance.  Although no significant effect was observed in either crop, mean yields for both species were greater in tillage treatment plots.  The tilled green bean yield mean was 21% greater than the no-till mean.  Okra showed a 23% increase in yield with the tillage treatment.

In 2020, the tillage treatment showed a significant effect on green bean yield, resulting in a 64.67% increase between treatments (Figure 5).  Okra did not show an interaction between tillage treatments, but the tillage mean showed a 40.62% increase over no-till.  When combining tillage and cover crop treatments, statistical significance is found in green bean yields.  Plots 1, 2, and 3 (tillage plots) showed higher means than no-till plots regardless of cover crop treatment

(Figure 6). Tillage and cover crop treatments had no significant effect on okra yields, although means from tilled plots were greater than no-till plots, regardless of cover crop treatment.

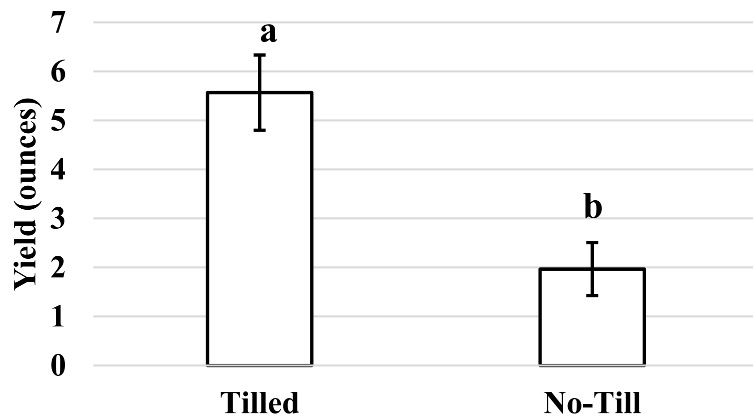


**Figure 5.** 2020 green bean yields in tillage treatments. Values are means ± SE, n=12. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method).

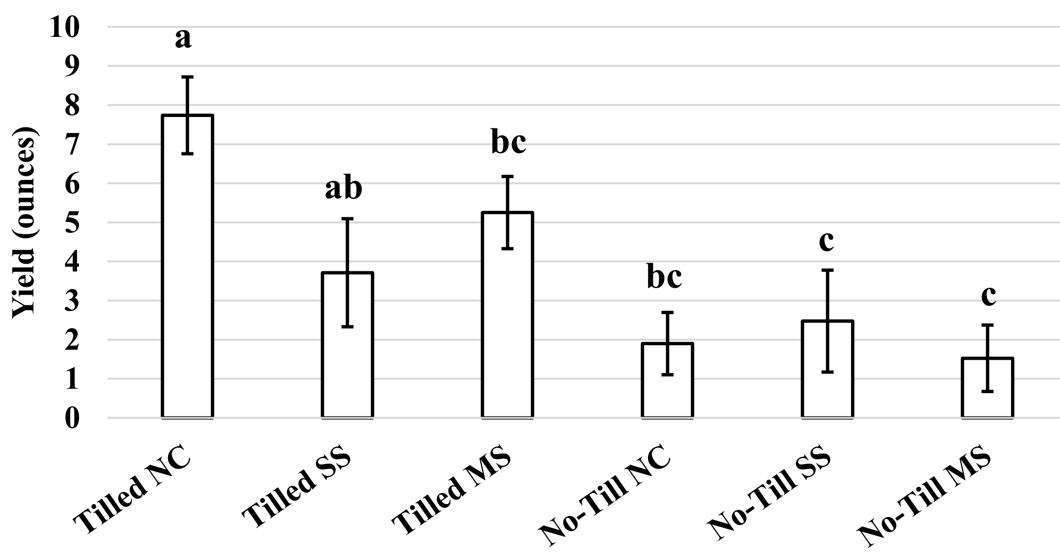


**Figure 6.** 2020 green bean yields in tillage and cover crop treatments. Values are means ± SE, n=4. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method). NC = No cover, SS = Single species, MS = Multi-species

**Plant Average Daily Growth**

In 2019, the tillage treatment showed a statistical significance in green beans. Green bean average daily growth indicated a block effect, but was terminated when blocks 1 and 2 were omitted from the model. This resulted in a significance between treatments and also showed a 19% increase in daily growth in the tilled treatment (Figure 7). The okra crop indicated no significance in growth rate, but also showed an 8.5% increase in tilled treatment yield.

In 2020, means of tilled plots were significantly greater in green beans (16.8%), showing an interaction between tillage treatments (Figure 8). Okra daily growth rate means were 7.02% greater in no-till plots, but were not statistically significant. The tillage and cover crop treatment revealed an interaction in green bean growth rates, although means from tillage plots (1, 2, and 3), were greater than no-till means, regardless of cover crop treatment (Figure 9).

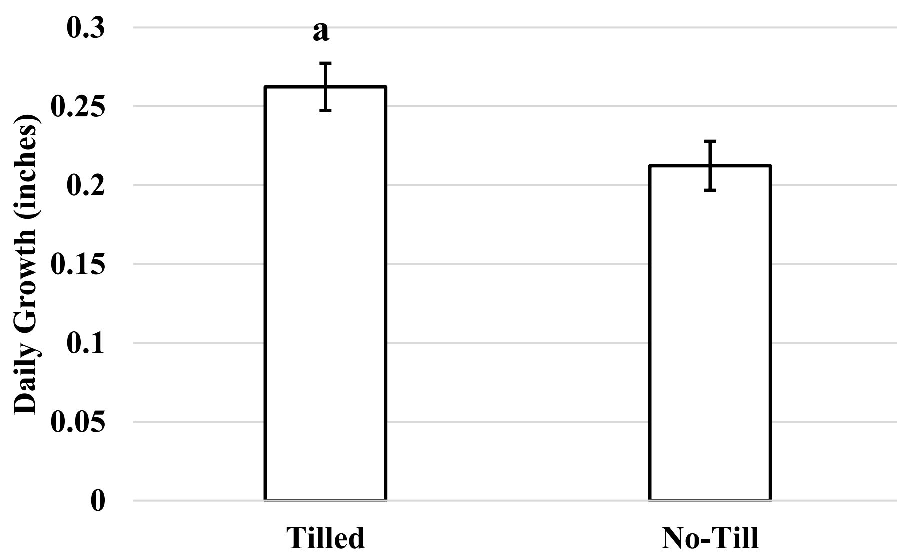


**Figure 7.** 2019 green bean average daily growth in tillage treatments. Values are means ± SE, n=12. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method).

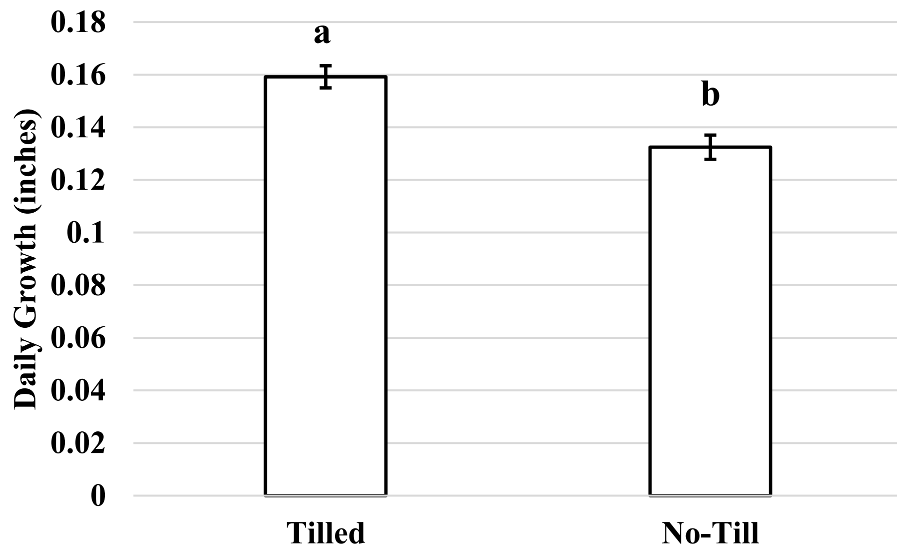


**Figure 8.** 2020 green bean average daily growth in tillage treatments. Values are means ± SE, n=12. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method).

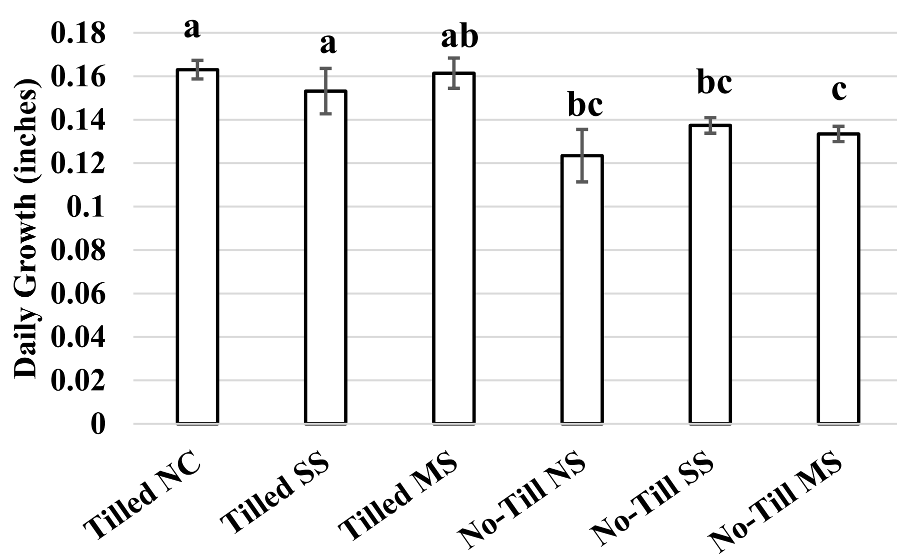


**Figure 9.** 2020 green bean average daily growth in tillage and cover crop treatments. Values are means ± SE, n=4. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method). NC = No cover, SS = Single species, MS = Multi-species

## Plant Nutrient Analysis

Initial analysis of 2019 samples indicated a block interaction in green bean Ca content. When blocks 1, 2 and 3, 4 were paired and ran separately, both pairs showed no statistical significance between tillage treatments. In green beans, the tilled treatment showed a greater mean average in P and K, 0.34% and 8.21% respectively. The no-till treatment had a greater mean average in Ca and Mg, 12.4% and 3.61% respectively. In okra, there were no statistical differences in treatments through any macronutrient tested. The tilled treatment showed higher concentrations of every nutrient investigated.

Phosphorus content in green beans under the tillage treatment was the only significant interaction in plant nutrients for 2020 (Figure 10). In green beans, the no-till treatment plots showed greater means for every nutrient when compared to tillage plots. In regards to cover crop treatments, the no cover crop treatments showed the highest content in beans for all nutrients tested. In the okra crop, no-till treatment plot means were greater in P, Ca, and K, although no values were significant. No cover crop treatments were significant in okra, but plots treated with a single species cover crop had higher means in all nutrients tested.

## Soil Nutrient Analysis

After statistical analysis, K content from tillage treatments was the only nutrient to show significance across all treatment methods. No-till treatment plots showed a % increase in means of lbs/A of K (Figure 11). Even though other nutrients did not show a significant interaction, no-till treatment plots reflected higher means for P and Ca, with a 7.96% and 12.54% increase respectively. Mg content in tilled plots showed an increase of 0.80% over no-till treatment plots.

Cover crop treatments and combined tillage and cover crop treatments indicated no statistical significance.

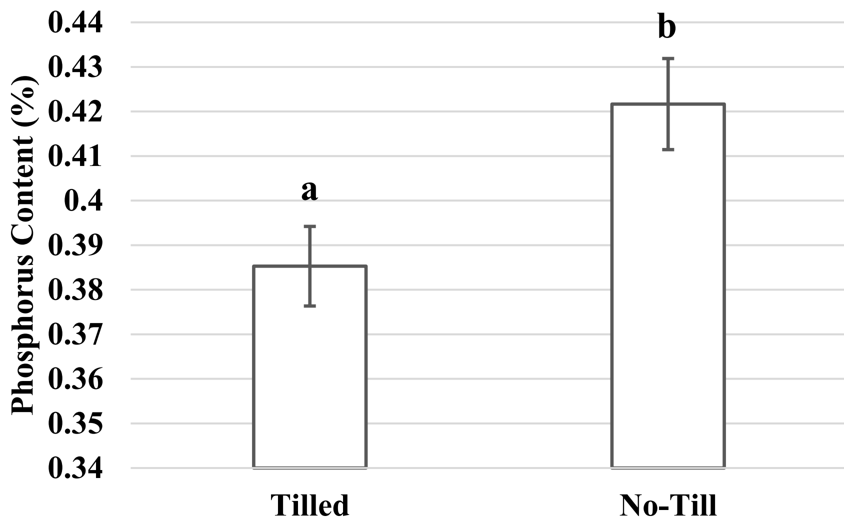


**Figure 10.** 2020 green bean phosphorus content in tillage treatments. Values are means ± SE, n=12. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method).

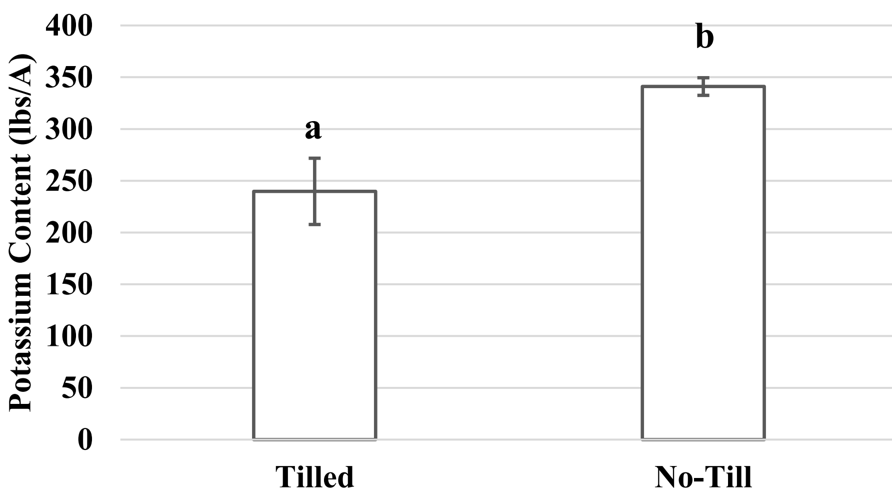


**Figure 11.** 2020 soil K content (lbs/A) in tillage treatments. Values are means ± SE, n=12. Values represented with the same letter are not statistically significant ($p < 0.05$, Fisher LSD Method).

# DISCUSSION

## Site Selection

Site selection at the Darr Agricultural Center poses benefits for relating this research project to landowners based on the topography and soil type of the site that is indicative to a typical landscape for this land use in the Ozarks. Soil type consistency will allow direct comparisons of physical and chemical changes in plot soils without the factor of various soil type characteristics and properties.

## Weather Data

Precipitation levels were greater in 2019 across all months. In 2019, Springfield received above-average rainfall totals for the months of May, June, and August. The 2020 growing season only experienced above-average rainfall in May. This could be one contributing factor to the decrease in green bean and okra yields between 2019 and 2020, as well as the decreased average daily growth. Temperatures showed no drastic differences from the 30-year average throughout the growing season in both years.

## Plant Yields

No significance was found between tillage treatments in either green beans or okra in 2019, although tilled plots showed the greater mean averages in both years of the study. It is not surprising that yields in tilled plots exceeded no-till plots in the first two years of production. In two growing seasons, negative impacts on tillage will not be seen as soil structure becomes more degraded as time increases. When tillage is first introduced, soil conditions are favorable to

plants due to a well-prepared seed bed and greater increases in soil temperature in the early growing season, which both aid in germination. If this study would be continued over multiple years, it is possible for the production of tilled plots to slowly decrease and eventually be surpassed by no-till plots, especially plots under cover crop management. When cover crops were introduced in the fall before the 2020 growing season, tillage plots showed greater means regardless of cover crop treatment in both green beans and okra. Tilled plots produced significantly greater yields in green beans, which indicates that the tillage treatment had a greater impact on production than cover crop treatments. This could be because of the lack of time needed to observe a benefit from cover crops in regards to physical growing conditions and nutrient cycling.

**Plant Average Daily Growth**

Similar to crop yields, average daily growth for both crop varieties were greater in plots under tillage in 2019, although only green beans growth rates were significant. Results from 2020 showed that green beans followed the same trend as in 2019 by showing a significance in tillage treatments, but varied from 2019 with okra. It is unknown why no-till plots indicated a greater growth rate in 2020, even though it shows no statistical significance. In this study, vertical height was the determining factor for growth. Additional measurements, such as leaf area and plant canopy coverage, would have been beneficial to more accurately assess physical plant health. Plant height could be influenced by competition from surrounding vegetation causing greater height growth, but lack in width, resulting in a less-favorable plant and the possibility to reduce production. It is not expected for no-till plots to outperform tillage plots in this area of interest in a two-year timeframe.

## Plant Nutrient Analysis

Initial analysis on Ca content in green beans showed a significant effect between blocks, but when blocks were separated and ran in groups of blocks 1,2 and 3,4, no significance was found. A possible explanation for this is the previous land use of the site. Several years before the incorporation of this research project, nearly half of the site was used for blueberry production. Once blueberries were removed, heavy lime applications were used to raise the pH of the soil for the continued production of the land. This coincided with blocks 3 and 4, which may provide a possible answer to why those blocks were significantly higher than blocks 1 and 2.

The 2020 growing season showed only P content in green beans to be significantly greater in no-till plots, which had an 8.63% increase over tilled plots. It is currently unknown as to why this significance is occurring. Continued research would indicate if this is a continuing trend. When observing cover crop treatments, we find that plots treated with no cover crop provided the highest mean content of all nutrients tested in green beans, but in okra, the single species cover crop treatment showed the greatest means although none were significant. One explanation as to why cover crops would alter nutrient content between crops is rooting depths. A study conducted by Weaver and Bruner (1927) from the University of Nebraska showed that okra roots were able to expand deeper into the soil profile, possibly avoiding nutrient competition with the cover crop.

## Soil Nutrient Analysis

Given the short amount of time in this study, no significant differences were expected to be seen. However, tillage treatments had an effect on soil K content indicating that no-till plot

means consisted of nearly 100 lbs/A more than tilled plots, resulting in a statistical significance. Although not significant, no-till plots showed increased means over tilled plots in P and Ca, while Mg was marginally greater in tilled plots. A possible explanation for this could be microbial associations found in no-till soils that were absent in tilled soils. At the point in the study where soil samples were collected to be analyzed, tillage plots had undergone six deep tillage passes (PTO-driven tiller) and multiple tillage passes throughout the growing season for weed control. This could have severely inhibited earthworm and microbe community growth in tilled plots due to the frequent disruption of the soil. In no-till plots, soil disturbance was very limited, which could have aided in establishing greater microbial colonies that facilitated greater plant available nutrients.

# CONCLUSIONS

Understanding the beneficial and detrimental impacts agricultural practices have on our food is increasingly important. Organic agriculture has been made popular by refraining from using synthetic materials to aid in crop production, leaving tillage operations as the leading practice for planting and weed management. Although avoiding the use of chemical fertilizers and herbicides can be beneficial, soil degradation is a threat when it comes to organic practices. This study sought to highlight the short-term impacts of tillage and cover crops implemented into a newly established vegetable production operation.

Only green beans responded significantly to various treatments. Okra showed no significant response in any treatment making the easiest, most cost-effective treatment an appropriate decision. For short-term green bean production, tillage increased production in regards to physical areas of interest, such as yield and growth rate, making it a viable management practice. In this short of a study, cover crops had no effect on nutrient density or physical characteristics of either crop.

The increased production through tillage practices highlights the benefits this treatment entailed for short-term production. At least two or three more years of research is needed to provide an accurate representation of each treatment. The recognized long-term impacts of cover crop rotations and no-till operations could prove beneficial to vegetable production. Seeking to find crop-specific tillage treatments and cover crop blends that would optimize vegetable performance would be useful for improving plant health and performance as well as improving soil health for future generations.

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