INTERCROPPING AND DENISITY IMPACTS IN A LETTUCE AND CHARD AGROECOSYSTEM

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ABSTRACT

Intercropping and Density in a Lettuce and Chard Agroecosystem

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Conventional agriculture that uses machinery management, synthetic fertilizers, and pesticides, is a contributor to greenhouse gas emissions, reduction of biodiversity and soil health. Agroecological methods, such as intercropping, have the potential to make farming more sustainable, financially feasible and to be implemented on a large scale. Gaps in agricultural research have led to limited information as to how intercropped arrangements can be adapted to be as productive as conventional systems. This research evaluates the ecological and economic performance of a lettuce and chard agroecosystem, specifically investigating the impact that density and intercropping has on plant productivity and profitability. Both species were grown in monocrop and intercrop arrangements at recommended density of 6". The results from these plots were compared with the outcome of an intercropped arrangement at an increased density of 4". To determine the ecological dynamics of the crop systems, percent herbivory, soil temperature and moisture, leaf area index, plant growth, rooting length, width and mass and harvested biomass were measured. Stomatal conductance and chlorophyll inflorescence levels were measured throughout the growing cycle to monitor the level of plant stress and photosynthetic capability. The economic performance of the crops was calculated from the total harvested biomass of each crop, using the standard market price. Both intercrops overyielded when compared to the monocrops. The land equivalency ratio of the recommended density intercrop was 1.19 and the increased density intercrop was 1.26, indicating that the intercrop was able to produce the same yield on less land and therefore benefit land conservation in agriculture. Economically, the intercrops also outperformed the monocrops. Overyielding in the intercrops was driven by heightened photosynthetic ability and greater resource sharing. These results serve as evidence that intercropping lettuce and chard can improve land-use efficiency and provide a higher gross revenue to farmers, and due to reduced competition, crops can be grown in a higher density arrangement.

Keywords: Intercropping, density, agroecosystem, overyielding, economic value,

ecological productivity

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1. INTRODUCTION

The earth is experiencing the most extreme temperatures, the highest rates of land and soil disruption and the largest atmospheric carbon releases in human history (Solomon et al., 2009). Rapid climate change is increasing the need for human adaptation and mitigation of growing environmental stressors. Conventional agriculture is a major contributor to air and water pollution, carbon dioxide (CO_2) release, water and energy usage, and land degradation (Carlisle et al., 2019). Due to the sheer magnitude of the agriculture industry, valued at over one trillion dollars in the U.S. alone, and its overwhelming impact to natural ecosystems, there is an effort to implement agroecological methods on a large scale (*USDA ERS - Ag and Food Sectors and the Economy*, 2021). Agroecology embraces agriculture systems that promote biodiversity and emphasizes non-use of external synthetic inputs. In order to mitigate environmental issues, a shift from conventional agriculture practices to more sustainable systems that can benefit the profitability and resilience of farms is necessary.

A frequently used method to increase the biodiversity in farming systems and to capitalize on beneficial biological interactions is the practice of intercropping. Intercropping supports ecosystem interactions, soil health, naturally creates a balance of pest and predatory insects and conserves land use (Layek et al., 2018). Intercropping systems rely on complementary interspecific interactions and mutualism for the crops to successfully mature (Brooker et al., 2015). In intercropping systems, natural processes rather than external inputs are used to mitigate pest issues and increase fertility (Ning et al., 2017).

When choosing what crops to plant in an intercrop, the farmer must consider species combinations that increase positive interactions (e.g., pest control) while minimizing negative interactions (e.g., competition for limited resources). Secondly, it is important to breed plant species that will produce desirable traits. Farmers have found that transforming the patterns that plants are cultivated can affect the processes that occur in intercropping systems. By altering the spatial arrangement of crops, farmers can control the competition between the species. Intercropping systems can provide equivalent or greater yields than conventional agriculture and the quality of the yield is often improved which insures higher net profit (Bach, 1980) (Li et al., 2021). The majority of intercropping research focuses on maize production systems in conjunction with bean crops, as it is a proven effective method as corn shares many aspects of complementarity with legumes (Searle et al., 1981) However, little research has been conducted on other cash crops to find potential complementarity and there is a need for research investigating how intercrop arrangements can be adapted to be more productive.

Brennan (2013) found that farmers have the ability to control competitive dynamics and herbivory by managing the density of the crops. The ideal density at which plants should be grown in order to benefit economic and ecological dynamics has been established for conventional monoculture systems. However, there is a need to find the most productive density to grow common cash crops within intercrop systems, which could allow for their implementation on a larger scale.

San Luis Obispo is a relevant location for climate adaptive agriculture systems and the necessity for sustainable systems that include lettuce is increasing. The majority of lettuce sold throughout the United States (U.S.) is cultivated in California, and lettuce remains a popular cash crop for farmers on the California Central Coast. The local climate provides ideal abiotic conditions for lettuce cultivation. However, the San Luis Obispo microclimate is projected to be characterized by more extreme seasons with ongoing climate change (Lenihan et al., 2003; Loarie et al., 2008). Colder and wetter winter seasons, accompanied by hotter and drier summers with drought potential, will have adverse effects on lettuce production as it is a year-round crop (Lafta et al., 2017). Utilizing vegetable intercropping systems in San Luis Obispo may lead to less crop devastation and more consistent yields under increasing climate change pressures. There are no publications about how lettuce density can affect productivity or alter ecologic dynamics within vegetable intercropping systems in the Central Coast. This knowledge gap challenges our ability to promote lettuce intercropping in this region.

I seek to understand how increasing the density at which lettuce and chard are planted at will impact both species' economic and ecological productivity and to test if intercropping is more beneficial than monocropping for these species. Conclusive results about the optimal density to plant lettuce and chard in intercrops serves as important information for vegetable farmers that are seeking a feasible manner in which they can sustainably farm. I hypothesize that planting the lettuce and chard in the intercrop will benefit plant growth and economic return. I anticipate that the intercrop will overyield when compared to the monocrop. I also hypothesize that the intercrop planted at the higher density will be more ecologically and economically viable when compared to a monocrop and intercrop planted at the recommended density.

2. LITERATURE REVIEW

2.1 Agriculture's Environmental Degradation

Large-scale modern agriculture dramatically changes the natural environment, and these altered abiotic conditions are in turn transforming the growth process of crops. The impacts of climate change such as untypical seasonal temperature, and changes in the amount of precipitation and solar radiation received will influence crop production (Malla, 2008). The world's population is predicted to increase by 34% by 2050 and will result in a greater demand for food, fiber and biofuel, which will add stress to the already limited global agricultural resources (Tuzel & Oztekin, 2018). Currently, the U.S. primarily relies on conventional agriculture systems that contribute to biodiversity loss, increased pollution, climate change and mass destruction of land and soils (LaCanne & Lundgren, 2018).

Emissions

Annually, domestic conventional agriculture emits approximately 698 million metric tons of carbon equivalent greenhouse gases (Sands, 2020). Of these emissions, 12.3% are carbon dioxide, 36.5% are methane and 51.4% are nitrous oxide. The agriculture industry is responsible for a total of 10.5% of all greenhouse gas emissions (Sands, 2020). U.S. agriculture is the fifth largest greenhouse gas emitter of any economic sector (Sands, 2020). In crop agriculture, emissions are reduced through sustainable farming methods that include less land clearance, more efficient water management, no-till farming, and the non-use of machine reliant systems and synthetic fertilizers (Jain, 2015).

Land Use

Deforestation for farming purposes, soil erosion and mechanized farming techniques increase atmospheric carbon emissions, which lead to expedited climate change (Shukla et al., 1990) The U.S. Geological Survey reports that 4.62 billion acres are being farmed globally. The U.S. is responsible for approximately 8.9% of the total land farmed, ranking second globally for the most land used for crop agriculture (*Map of Croplands in the United States*, 2015). The market for crops is dominated by few species; conventionally grown corn and soybeans account for 50% of all of the cropland harvested in the United States (*USDA – National Agricultural Statistics Service*, 2012.). Organic farming remains a small share of the cropland in the U.S., contributing 1% of the total cropland farmed. California hosts the most organic cropland in the nation and represents 21% of the total organic cropland domestically (Bialik & Walker, 2019).

Soil Health and Degradation

Soil degradation is a pressing socioeconomic and environmental problem as it is a threat to food security and environmental integrity (Altieri & Letourneau, 1982). Approximately 95% of all of the food produced for humans and animal agriculture depends on soil for cultivation (Panagos et al., 2016). As feeding the increasing population is a growing concern, and available land is starting to dwindle, the supply of fertile, stable soil is in higher demand.

Yang et al. (2020) defines soil health as the capacity for soil to function within an ecosystem, to sustain crop productivity and maintain or enhance environmental sustainability. Agricultural soil degradation is most directly caused by intensive tillage fossil fuel consumption, draining of wetlands, use of agricultural machinery, fertilization, and pesticide management (Altieri & Letourneau, 1982).

Monocropping causes adverse effects on soil health. Undiversified systems continually grow the same species of crops for multiple seasons, which leaves the soil void of plant growth nutrients. By growing the same crop in successional seasons, the crop continues to take the same resources from the soil without replenishing them. Along with unbalancing soil nutrient contents, monocropping increases the likelihood of low diversity in functional soil microbial communities and plant specific soil-borne pathogens (Bai et al., 2019).

2.2 Agroecology

Agroecology emphasizes non-use of external synthetic inputs and agriculture systems that promote biodiversity by mimicking the patterns and processes of natural ecosystems. By creating diversified cropping systems, farmers are able to increase resilience to changing abiotic and biotic stressors, and support soil health, and the conservation of natural resources (Tuzel & Oztekin, 2018). Diverse systems decrease pollution, pest and disease issues, and dependence on external inputs. Crop biodiversity provides the ecosystem with services beyond the efficient cultivation of food (Altieri, 1999). According to Björklund et al. (2014), the services that agroecosystems can provide to the natural environment come in three forms. Firstly, the direct support of agricultural production through soil fertility and biotic regulation mechanisms, such as pollination, biological control of pests and weed competition. Soil nutrients and fertility are enhanced through crop species richness and high functional diversity (Bardgett & van der Putten, 2014). Secondly, agroecosystems benefit the quality of life for humans through enhancement of farm aesthetics which add value to landscapes. Lastly, agroecology contributes to a global lift supporting functions such as availability of clean water, management of biogeochemical cycles and conservation of biodiversity (Andersen et al., 2007; Bjorklund, 2014). Agroecologists aim to introduce diversity into their agriculture systems through four main approaches: intraspecific genetic diversity, cultivation of new/alternative crops, mixed crops (intercropping) and crop rotation (Tuzel & Oztekin, 2018). Through agroecology, agriculture systems can adapt the changing environment through natural methods which will mitigate crops' vulnerability to the changing climate.

2.2.1 Intercropping

Intercropping is a popular agroecological method that increases crop biodiversity by planting two or more crops in the same plot and cultivating them simultaneously (Ofori & Stern, 1987). Increased diversity systems have a direct relationship with the number of ecosystem functions the system will provide (Andersen et al., 2007). Through interspecific interactions, crops can use light, water, and nutrients more efficiently than less diverse systems (Andersen et al., 2007). The goal of intercropping is to facilitate natural cycles that will provide the plants with resources, rather than having to rely on external inputs and heavy management for crop growth, which would typically be a large expense for farmers.

<u>Intercropping Arrangements</u>

There are four common intercropping arrangements: mixed intercrops, row intercrops, strip intercrops and relay intercrops (Andersen et al., 2007). In mixed arrangements, the crops are grown with no distinct row arrangement, species are intermixed with one another according to a randomized order. Row intercropping cultivates species in distinct rows, often planted in an every-other row arrangement. Strip intercropping cultivates the same crop in sequential rows followed by rows of the next crop. Lastly, relay intercropping grows crops at different stages of growth, but their growth cycles overlap, one crop is planted and once it begins to mature, the next plant is added into the system (Andersen et al., 2007).

Impacts to Soil

Intercropping is a successful method for sustaining soil health and stability, controlling runoff and nutrient losses **(**Letourneau & Bruggen, 2006). Including crop diversification in agriculture, reduces soil-borne disease and soil erosion, while increasing nutrient and water use efficiency, biodiversity, and functional soil microorganisms (Yang et al., 2020). Intercropping can also increase the soil's physical structures and heterogeneity of chemical nutrients, which is beneficial to both soil health and crop yields (Bardgett & van der Putten, 2014). Conventional agricultural practices tend to leave plots of land bare once the crops are harvested, which has adverse effects to the soil infiltration rate (Basche & DeLonge, 2019). Leaving the soil vulnerable to the abiotic environment negatively impacts the ability for soils to absorb and retain water. Intercropping has fewer negative impacts on soil infiltration because there is less time that the soil is left bare before the cultivation of new crops. This is due to multiple crops being grown simultaneously and harvested at differentiated times. By selecting plants for intercropping that come from different functional groups, such as a C4 plant and a C3 plant, heterogeneity of soil functional microbes is created (Vukicevich et al., 2016). A frequent combination in intercropping systems is legumes which can fixate nitrogen into the soil and a non-leguminous forb that uptake the nitrogen (Vukicevich et al., 2016). By intermixing these functional groups, it offsets the need for external nitrogen inputs for the non-leguminous plant. In an experiment conducted in Pernambuco, Brazil, the soil health of a monoculture of cassava and an intercrop of cassava, pigeon pea, and legumes was compared. The intercrop reported a 50% reduction of black root rot in cassava when compared to the monocrop. The intercropped soil had a higher organic carbon content, microbial biomass, and more enzyme activities than the monoculture. These factors are associated with a decline in soil-borne diseases and disease severity in the intercrop (Medeiros et al., 2019).

Pest Prevention

The introduction of more diversity in agriculture systems through intercropping can reduce the population of pests (Bach, 1980). Biological control can reduce pest populations rather than pesticides or insecticides by selecting crops that will provide natural predators for pests. Cultivating alyssum with broccoli is an example of biological control in intercropping. Alyssum is often planted with crops that attract aphids, because the alyssum attracts hoverflies which prey on aphids (Brennan, 2016). When alyssum is planted in rows with a 1:1 ratio of broccoli, the number of aphids is significantly reduced in comparison to the sole crop of broccoli (Brennan, 2016). When external inputs are added to agriculture systems, there is a loss of above ground diversity in terms of insects, which directly reduces the number of beneficial predatory arthropods and birds that prey on pests. External inputs also negatively affect the diversity of belowground arthropods, nematodes, fungi and bacteria (Letourneau & Bruggen, 2006). By introducing more diversity to the system through intercropping and not relying on inputs for pest control, intercropping systems can function more similarly to natural ecosystems and support biodiversity in animal species.

2.3 Selection of Crops

Economic Viability

When selecting crops for cultivation, the economic productivity is an important factor for farmers. The economic viability can be determined from the market demands relative to production costs. A farmer must ensure that there is a market demand for the crop in order to be economically profitable. A crop is economically beneficial when the price of cultivation is less than the financial gain of selling the crop. The economic viability is also based off of the predicted yield and the quality of the yield. The yield from an organic seed, without synthetic inputs, should be large enough to provide a positive net income (Tuzel & Oztekin, 2018).

Complementarity, Facilitation and Competition

A deciding factor for crop selection in an intercropping system is the quality of the interspecies interactions between the crops (Andersen et al., 2007). According to Goldberg (1990), the interactions between species should be analyzed from the effect that each species has on the availability of limiting environmental resources and the response that each species has to changes of the availability of the intermediaries.

Three aspects of interspecies interactions that are important to consider when selecting crops are complementarity, facilitation, and competition (Andersen et al., 2007). Complementary crops being cultivated together in intercrop systems lead to better resource sharing than in monocrop systems (Vandermeer, 1992). Complementarity can appear in phenological variations that allow crops to use resources during staggered growth stages or morphological differences (e.g., variations of root type and depth that allow for greater nutrient uptake and below-ground space-sharing) (Corre-Hellou et al., 2006). Facilitation occurs when intercropping species allow for an easier route of growth than monocropping would (Andersen et al., 2007). The facilitative production principle explains facilitation as crop A in an intercropping system benefitting from the presence of crop B, without positively or negatively affecting crop B (Vandermeer, 1992). An example of this interaction is legumes supplying nitrogen and solubilizing phosphorus, which can be used by other crops, while the beans are not negatively affected by the other crops. The last aspect of interspecific interactions is competition, which occurs when there is a mutual need for a resource that is in limited supply, this leads to a reduction of productivity for one or all of the crops (Begon et al., 1996). If the demands for resources are varied among species, the competition is relatively low within intercrop arrangements. Monocropping can have high competition as the same species of plant is competing with other members that have identical environmental needs (Andersen et al., 2007). Finding species that promote complementarity and facilitation for rationing resources is critical in intercropping, because in a system void of these qualities, competition is heightened which will reduce the productivity of the crops.

2.4 Arrangement Impacts on Productivity

Density

Brennan (2013) discovered that farmers can control competitive dynamics and pest interaction by managing the density of the crops. When the plants are cultivated at a higher rate of density, there is an increase in pollinator interactions with the crops. In a research study that followed an intercrop with cocoa and plantains, when the plantain was cultivated five times denser than that the control plot, the number of pollinating midges increased two-fold (Brooker et al., 2015). However, an increase in the density of intercrops can negatively influence interspecific competition via heightened need for space and resources, this can reduce the yields of the crops (Chui and Shibles, 1984). Density can impact interaction with pest populations. In an experiment conducted to decipher the affects that density can have on pests, researchers studied a crop field with monocrops and intercrops of varying densities. The results reported that there were 10 - 30% more cucumber beetles in the fields that were monocropped and planted at a lower density (*Yield Responses of Intercropping Systems*, n.d.). There is little research analyzing the impacts that density has on total yield within intercrops. In a research study completed on an intercrop with cassava and gourds, the density at which the gourds were cultivated at was increased and decreased to test the reaction of the cassava yield. The yield of the cassava was the lowest when the gourd was planted to the highest density. Yet the cassava yield was greatest when the gourd was planted at the medium density (Doubi et al., 2016).

Yield Impacts

The quality of the yield intercrops provide can insure higher gross revenue than monocrops (Bach, 1980). Relay intercropping has been proven to change potential yield through the extension of the growing season. Relay intercropping allows for greater amounts of light capture which results in a larger yield (Zhang et al., 2008). The yield of intercrops is increased through the complementarity between species during times of low resource availability, such as water and nitrogen (Stomph et al., 2020). The marketable yield of crops is heightened by biological control of pest populations and disease contamination in intercropping systems (Boudreau, 2013). With more diversity in intercropping systems, the different species of crops have varied reactions to abiotic and biotic changes. The diversity can result in compensation responses that can limit yield loss in intercrops in comparison to the loss that would be experienced in sole crops (Stomph et al., 2020).

Photosynthetic Productivity

Analyzing photosynthetic properties of plants such as stomatal conductance and chlorophyll fluorescence give insight to the stresses that crops may be experiencing. Stomatal conductance to water vapor (gsw) measures the degree to which the stomata are opening to allow for the exchange of water vapor and carbon dioxide. When crops are under water stress, the degree to which their stomata open to allow gas exchange between water vapor and carbon will be reduced, as less water is available to swell guard cells. In research with a tree-grass intercrop, when water deficiency was experienced and the soil moisture content falls below field capacity, lesser photosynthesizing capabilities were noticed (Forey et al., 2016). A crop's level of photosynthesis can give insight to the competition for resources, space and light that the crops may be experiencing. In theory, more competition is witnessed between the same species of crops than in a diversified system. However, in an intercrop, one species can crowd and dominate the plot and photosynthetic properties will be reduced. In intercrop arrangements, there is the potential for heightened shading due to an increased canopy cover, which can lead to reduced photosynthesis productivity (Reynolds et al., 2007). Chlorophyll fluorescence can be analyzed to determine if the plant is undergoing stress as the absorption and reflection of light will be to a lower degree. Chlorophyll fluorescence measures the portion of light that is absorbed by photosystem II in order to conduct photochemistry. As intercrops are intended to be less competitive, chlorophyll fluorescence should be increased.

3. METHODS

3.1 Experimental Design

This experiment was conducted at California Polytechnic State University, San Luis Obispo from April 7th to June 2nd, 2021. The location of this experiment was the Student Experimental Farm (SEF), a two-acre farm located in the Northeast quadrant of the university's campus. This research was positioned within a fenced-in region of the farm that contains 32 8' by 4' raised beds. Each of the raised beds were filled with a soil mix consisting of 40% (by volume) composted manure, 40% sand and 20% coconut coir. The soil texture within the raised beds was sandy loam, with an average compaction depth of 21.7 centimeters, pH of 7, and infiltration rate of 597.8 inches an hour.

Calibrated drip line irrigation was provided for regular watering of the crops, each bed was given three drip lines. The watering regime consisted of three 40-minute watering sessions throughout each week. The beds were subsidized with additional overhead irrigation prior to predicted high heat events.

Organic seeds of Salanova lettuce (*Lactuca sativa*) and Bright Yellow swiss chard (*Beta vulgaris)* were purchased from Johnny's Selected Seeds. These species were selected because they have varied architecture which limits competition for space. The lettuce grows low to the ground, spreads out on top of the soil, and has shallow roots, while the chard has a longer shoot and produces deeper roots. The seeds were planted into greenhouse trays on March 8th, 2021 and transplanted into raised beds on April 7th, 2021.

There were four treatments tested in this experiment, monocrops of each species at the recommended density of 6", row intercrops at 6" density, and row intercrops at a high-density of 4" (Figure 1); each treatment was replicated in eight raised beds (N = 8), with a randomized block design (Figure 2).

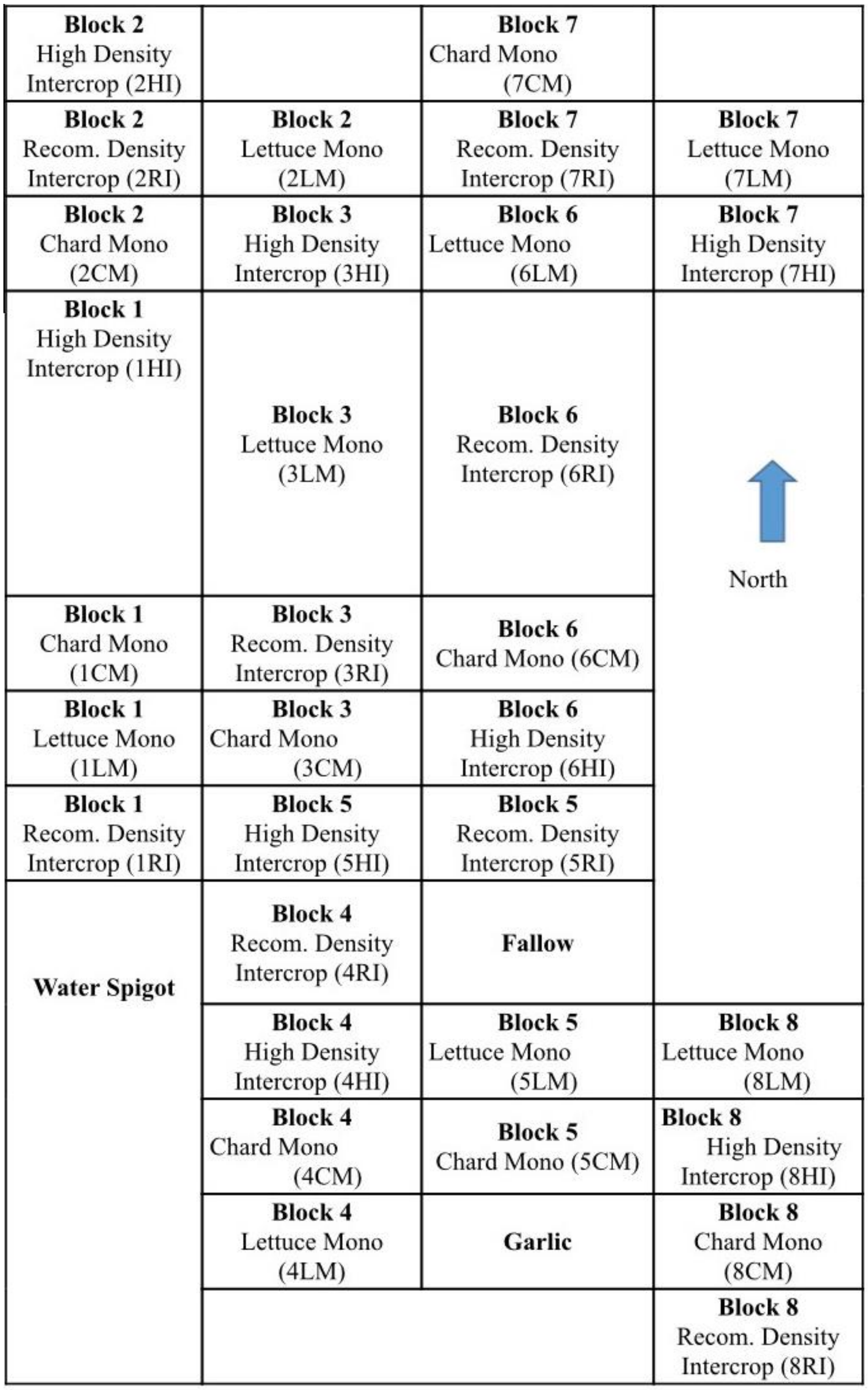

Figure 1. Layout of the experiment containing eight blocks with four raised beds/treatments per block

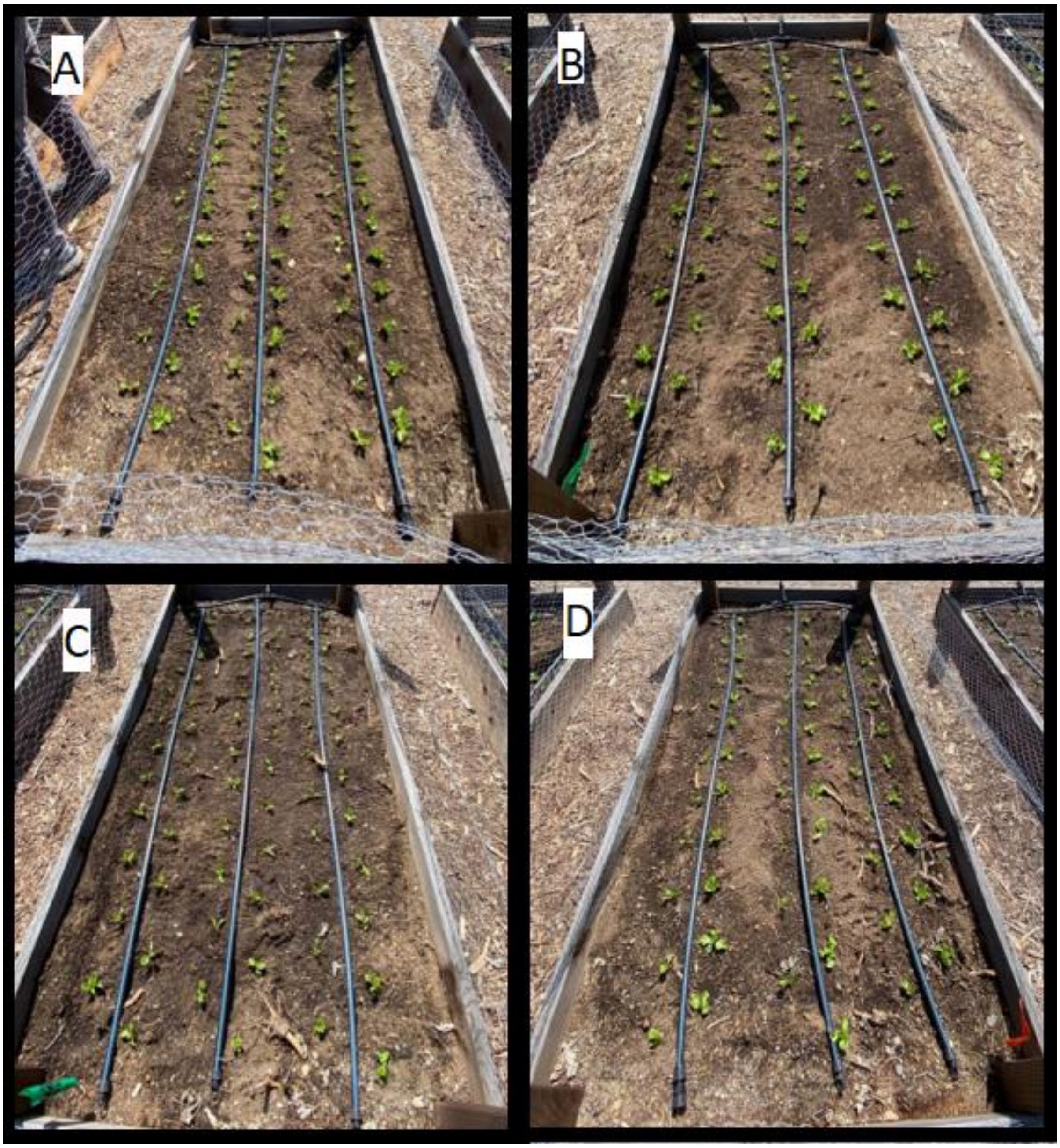

Figure 2. The crops on 4/7/2021, directly after transplanting, intercropped at a high-density of 4" (A), lettuce monocrop (B), chard monocrop (C) and intercropped lettuce and chard planted at the recommended density of 6" (D)

The sample size was a total of ~2500 lettuce and chard crops cultivated across all 32 beds. However, the sample size was altered dependent on the method being implemented. The sampling frame includes the soil in which the crops grew in as it will be a determining factor of how the plant arrangements impact the soil health.

<u>Plant Height</u>

The plant height of crops in the center two rows of each raised bed was measured in centimeters using a standard ruler. The crops were measured in their ambient position from the top of the soil to the tallest part of the plant. Within the monocrops, every other plants' height was measured in the two middle rows. In the intercrop treatment, every plant in the middle rows was measured and the height was recorded separately by species. This process was repeated within each raised bed until 10 plants of each species were measured (10 total measurements in the monocrop treatments and 20 measurements in the intercrop treatments). This measurement was recorded twice during the experiment period during week three and eight.

Herbivory

Reduced herbivory in intercropping can lead to more economic profitability from higher quality yields (Altieri & Letourneau, 1982). The percentage of herbivory created by interaction with pest populations was observed via visual estimation. For every plant that was measured for height (10 total measurements in the monocrop treatments and 20 measurements in the intercrop treatments), a leaf from the plant was chosen for herbivory observation based off a randomized number list. Once the leaf was selected, it was visually inspected to estimate the percent of herbivory by pests. Each leaf was observed for at least 30 seconds. This measurement was recorded twice during the data collection during week three and eight.

Leaf Area Index

Leaf Area Index (LAI) is a measurement of the total surface area of the leaves of a plant per ground unit area. This measurement is an indication of the fullness of the canopy and how efficiently the crops are capturing sunlight (Babin, 2021) In order to conduct this measurement, a tape measure was secured from the SE to NW posts of each of the crop beds. LAI was collected at 10 transects along the tape measure at 40, 60, 80, 100, 120, 140, 160, 180, 200 and 220 centimeters. A 4' string with a weight attached to the end was lowered into the crop beds until the weight made contact with the soil. The number of leaves that touched the string were counted. This measurement was recorded twice during the data collection period during week two and week eight.

Stomatal Conductance and Chlorophyll Fluorescence

Stomatal conductance and chlorophyll florescence give insight to photosynthesis efficiency and water stress among the crops (Miyashita et al., 2005). Stomatal conductance and chlorophyll fluorescence were measured seven times at 11am on Tuesday and Thursday from week three through week eight. There were five dates that were excluded from this sampling because the crops had been recently harvested and the new leaves were too small to accurately sample.

Eight plants of each crop were randomly selected in each raised bed of blocks 1-4 to sample. Therefore, in monocrop treatments, eight measurements were taken (two per row) and in the intercrops, there was a total of 16 measurements, eight for each crop (four per row) (Figure 3). The plants were marked with white flags to indicate which crops were to be included in this method. By measuring plants in each row, microclimates were accounted for within the raised beds.

A LI-600 Porometer and Fluorometer (LiCOR) was used to record stomatal conductance and chlorophyll fluorescence levels. The LiCOR instrument was clamped onto the newest fully expanded leaf of each selected plant with a minimum leaf length threshold of 2”, and the data was displayed on the screen of the instrument.

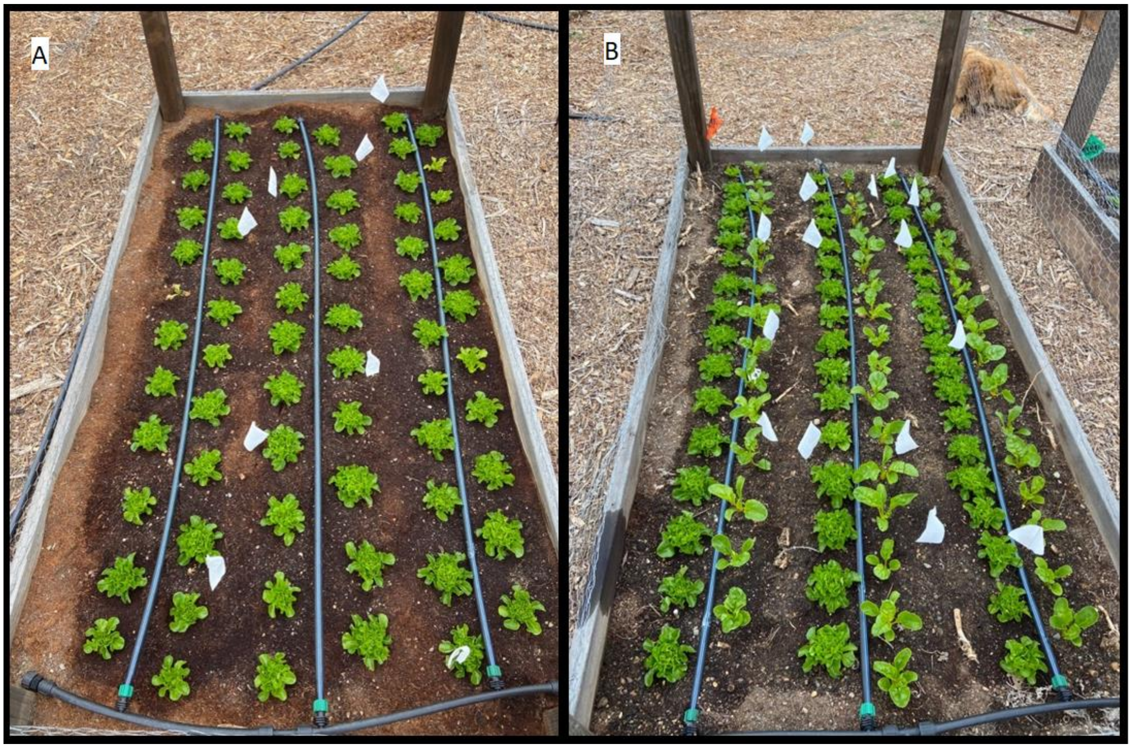

Figure 3. White flags indicate which plants to sample for the stomatal conductance and chlorophyll fluorescence methods in the lettuce monocrop (A) and high-density intercrop (B)

<u>Root Measurements</u>

The roots of the plants in blocks 1-4 that were selected for the photosynthesis measurements were sampled at the end of the growing period for fine root biomass, width and length. In blocks 5-8, eight of each crop were randomly selected in each bed for root sampling. The roots were carefully removed from the soil by digging a trowel in a circular motion approximately 4 inches from the base of the crop. Once loosened, the plant was gently pulled up to expose the roots. The roots were lightly shaken to allow for loose soil to detach. The width and length of the roots were measuring using a standard ruler in centimeters. The length of the roots was measured from the root collar to the tip of the longest root. The width of the roots was measured in centimeters across the widest part of the root ball. After the first two measurements, the roots were sprayed with water over a screen to allow dirt to detach and were left to dry for five minutes. This allowed for the wet mass of the roots in grams to be measured on a scale. The roots of each crop in each treatment across all blocks were combined and weighed together.

<u>Soil Temperature and Moisture</u>

A Time Domain Reflectometry (TDR) probe was used to examine the soil temperature and moisture content within each treatment. The probe was pushed into the soil at five areas 40 centimeters apart along the SE to NW transect. This measurement was collected twice during week two and week eight.

Yield

In order to determine the intercrop's ability to overyield, the lettuce and chard were harvested throughout the growing period and the sellable biomass was weighed using a scale and measured in grams. Using scissors, the mature, outer leaves of the chard were cut, leaving the younger, center leaves to mature. Using a knife, the lettuce was cut approximately two inches above the root collar and the leaves were collected to be weighed. The biomass of each species in the treatments were weighed separately. The chard crops were harvested three times during weeks five, six and eight. The lettuce was harvested twice, during weeks five and eight.

Land Use

To determine how much land would be needed to produce the same amount of yield in a polyculture as in a monoculture, Land Equivalent Ratios (LERs) were calculated conducted based off of the total biomass data (Mead & Willey, 1980). This calculation provides an intercrop's ability to overyield based off the same unit of land when compared to a monocrop counterpart (Equation 1).

$$\text{Eq. 1 } LER = \sum (Ypi/Ymi)$$

Ypi = yield of each crop in the intercrop

Ymi = the yield of each crop in the monoculture

The ratio of Yp/Ym for a particular crop gives the partial LER. When the partial LERs are combined, it gives the total LER. When the combined LER for each crop is greater than 1, it is an indication that the intercropping supports the growth and yield of a species more than sole cropping (Doubi et al., 2016). Therefore, more land would be needed in a monoculture to produce the same yield as the intercrop, and the intercrop would have a yield advantage over the monocrop. The partial LER was crucial to this experiment as it was important to acknowledge the productivity of each crop within each treatment as an LER of greater than 1 could be due to one crop performing extremely well in the intercrop and the other failing. LERs for each crop were calculated using the total biomass in monocrop, high-density and recommended density intercrop arrangements.

Economic Value

The economic value for both crops in each treatment was calculated in order to determine if growing the lettuce and chard in an intercrop is as profitable or more profitable than a monoculture system, as overyielding does not always ensure greater profitability. The crops were assigned economic values per pound based upon the USDA National Specialty Crops Organic Summary for June 1, 2021, with the lettuce valued at $5/lb and the chard at $4/lb (*National Specialty Crops Organic Summary*, 2021). The total yields for each treatment and crop in each block were converted into pounds (454 grams=pounds). The total yield in pounds of each crop in the monocrop and intercrops were multiplied by the economic value to calculate gross revenue.

Statistical Analysis

Data was recorded in Excel. For all results reporting on herbivory, root measurements, plant height, stomatal conductance, and chlorophyll fluorescence, statistical tests compare the effects of treatments on individual species. Therefore, the outcomes of lettuce were not compared with that of chard. This was done because the species were sampled separately for these methods. For yield, economic value, soil measurements, and LAI, the results of each individual species in the monocrop was compared with that of the intercrops including both species (i.e. the individual species within the intercrops were not analyzed). The results of these methods were applicable to both species in the intercrops, so they did not have to be analyzed separately. ANOVA tests were conducted for each day of data collection individually, as it is important to determine how the significance varies throughout the growing cycle of the crops to gauge how they adapt while reaching maturity. Statistical tests for the yield and economic value results compared each species in monocrop with the results of the recommended density and high-density intercrop treatments. All ANOVA tests were conducted within Microsoft Excel and the statistical significance was defined as $\alpha \leq .05$. A MANOVA excluding the least significant results (LAI, stomatal conductance, chlorophyll fluorescence) was conducted in R software to analyze the significance that all independent variables (herbivory, soil moisture, soil temperature, plant height and root measurements) had on the response variable (yield) at $\alpha \leq .05$.

4. RESULTS

4.1 Herbivory

The lettuce and chard experienced opposite trends in herbivory over time throughout each treatment. There was a decrease in the herbivory on the lettuce over time in each treatment (Figure 4). In the beginning of the experiment, the lettuce had the most observed herbivory in the recommended density intercrop and the least herbivory in the monocrop. However, once the plants had reached maturity, the lettuce the had most herbivory in the high-density intercrop and the least in the monocrop.

For the chard, there was an increase in herbivory over time across all treatments. Throughout the experiment, the chard reported more herbivory than the lettuce in any treatment. Similarly to the lettuce, the high-density intercrop treatment resulted in the most herbivory on the chard once the crop had reached maturity. The chard also experienced higher herbivory in the high-density treatment early on in the growing cycle. The monocrop treatment experienced the least amount of herbivory on throughout the growing cycle of the chard. The herbivory on chard in the recommended density treatment was lower than the monocrop treatment, which could indicate no negative interaction within the treatment. The changes of herbivory for either crop was not significantly affected by any treatments when analyzed in an ANOVA.

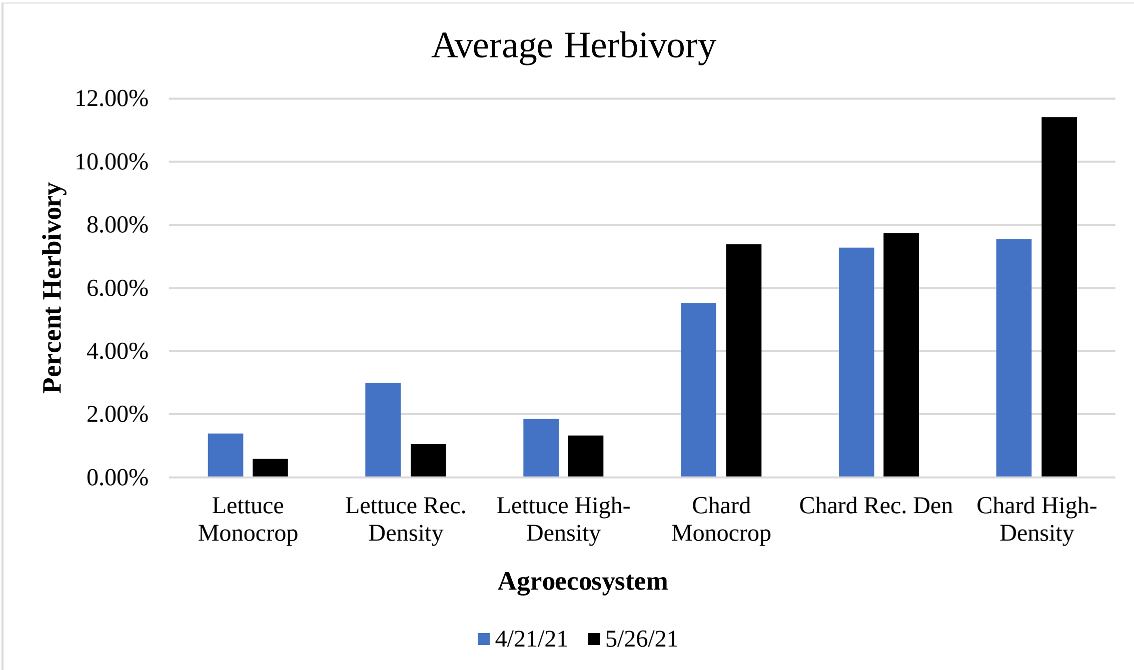

Figure 4. The average herbivory from all blocks of the crops in each treatment from two days of data collection

4.2 Leaf Area Index

Across all treatments, the LAIs of both crops increased with crop maturity (Figure 5). During the first observation, the high-density intercrop had the greatest LAI of any treatment with an LAI of 0.375. Meanwhile, the chard monocrop had the lowest LAI of 0.2. However, once the crops had matured, the lettuce monocrop had the greatest average LAI of 3.01 and the recommended density intercrop had the lowest LAI of 2.58. The LAI results indicate efficient space use and light capture in all treatments. While the treatments did report different LAIs, the range was small, only varying by .43 on the second day of data collection and was not significantly affected by the treatments when compared in an ANOVA.

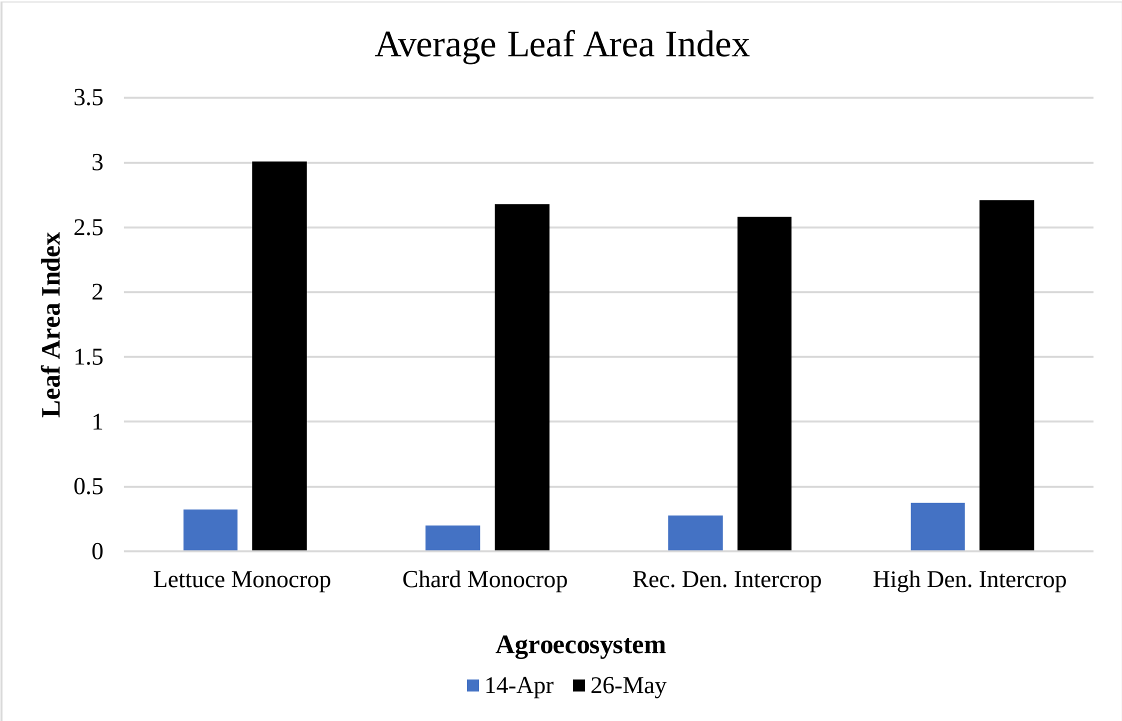

Figure 5. The average leaf area index of four agroecosystems in the beginning and end of the growing cycle

4.3 Plant Height

The height of the lettuce and the chard was relatively consistent across all treatments throughout the growing cycle (Figure 6). In the beginning of the experiment, the lettuce in the recommended density intercrop had the highest average height across all treatments. During maturity, the lettuce was tallest in the high-density intercrop. The range of average height across the treatments for the lettuce was 1.06 centimeters. In early growth, the chard was the tallest on average in the high-density intercrop treatment. Later in the crop growth, the chard was the greatest average height in the monocrop treatment. Both species experienced the greatest change in height in the recommended density intercrop. The plant height was not significantly affected by the treatment for either of the crops in the beginning or end stage of the crop growth when analyzed in an ANOVA.

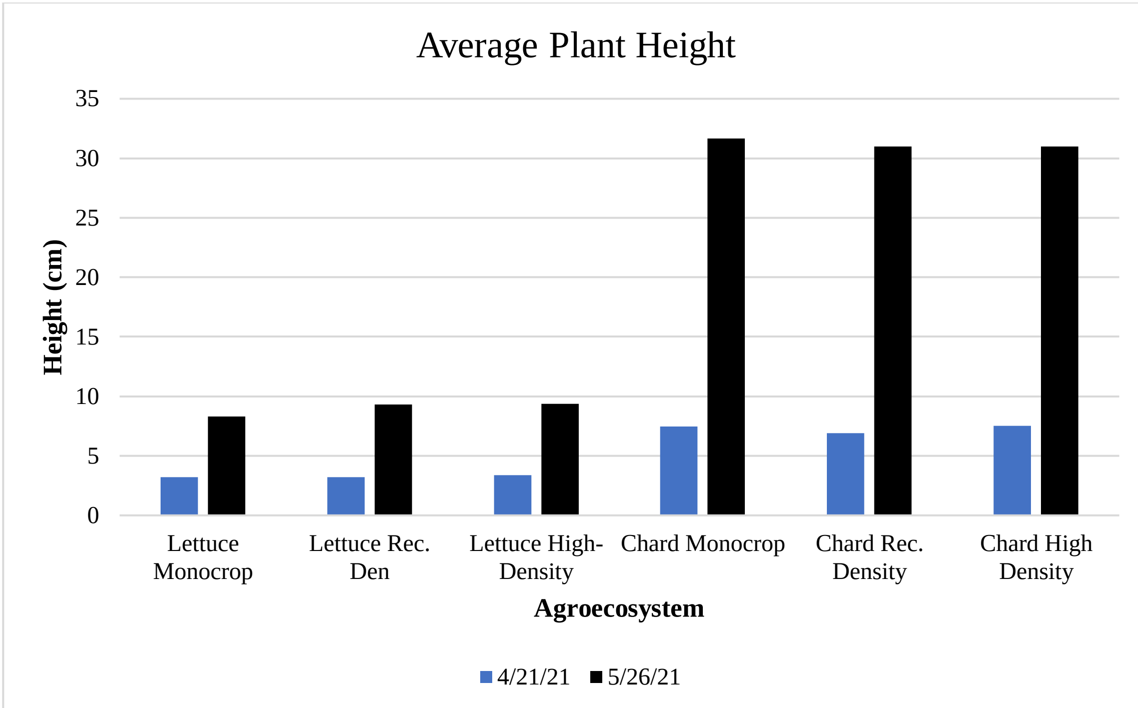

Figure 6. Average plant height of lettuce and chard in the four treatments on two days of data collection

4.4 Stomatal Conductance and Chlorophyll Fluorescence

The lettuce experienced the highest average stomatal conductance within the monocrop treatment, however, each individual day of data collection fluctuated with which treatment resulted in the highest levels of stomatal conductance (Table 2, Figure 7). On the third week of plant growth, the lettuce had statistically significant differences in the level of stomatal conductance across treatments ($p=.02$). When the lettuce began to reach full maturity, there was a decrease in stomatal conductance in the intercrop treatments and an increased in the monocrop. This may indicate that the lettuce is experiencing higher stress by being planted with the chard once reaching the full growth potential. An unexpected result is that the stomatal conductance is relatively high for the lettuce during high temperatures across all treatments. The stomatal conductance seems to be affected greater from reaching maturity alongside the chard than it does from high heat events. The treatment with the lowest average stomatal conductance for lettuce was the high-density intercrop.

The average stomatal conductance results for the chard indicate that this species did better in the intercrops as the chard had the greatest stomatal conductance in the recommended density treatment. Unlike the lettuce, there was not the pattern of stomatal conductance decrease as the plants reach maturity, which indicates that they were not as stressed as the lettuce. On the first day this measurement was conducted, the stomatal conductance of the chard was statistically significantly different ($p=.04$). This could indicate that the chard in the monocrop and high-density intercrop experienced greater stress from transplanting than that of the recommended density intercrop treatment. The chard in the recommended density intercrop had consistently higher levels of stomatal conductance than the chard in the monocrop. During high heat events, the chard had the best levels of stomatal conductance in the recommended density intercrop, which could indicate better water sharing when planted with the lettuce and with other members of the same species.

The chlorophyll fluorescence of the lettuce decreased over time across all treatments (Table 1). The lettuce chlorophyll fluorescence was potentially impacted by temperature as across all treatments the chlorophyll fluorescence was the highest during a low temperature event. The average chlorophyll fluorescence was the highest in the high-density intercrop and the lowest in the recommended density intercrop (Table 4). The average chlorophyll fluorescence levels within the chard mirrored that of the lettuce as the highest values were in the high-density intercrop and the lowest were in the recommended density intercrop. The chlorophyll fluorescence was not significantly affected by the treatment for either of the crops.

Table 1. The chlorophyll fluorescence of lettuce and chard in four treatments from every day of data collection.

Chlorophyll Fluorescence						
Date of Collection	4/22/21	4/27/21	4/29/21	5/4/21	5/20/21	5/25/21
Temperature (C)	11.7	18.1	30.1	26.2	17.4	16.8
Lettuce Monocrop	0.714	0.605	0.661	0.603	0.549	0.558
Lettuce Rec. Den. Intercrop	0.702	0.573	0.622	0.526	0.624	0.549
Lettuce High-Den. Intercrop	0.71	0.599	0.646	0.666	0.616	0.592
Chard Monocrop	0.706	0.64	0.64	0.704	0.628	0.692
Chard Rec. Den. Intercrop	0.704	0.591	0.695	0.54	0.641	0.673
Chard High-Den. Intercrop	0.7	0.635	0.687	0.686	0.644	0.701

Table 2. The stomatal conductance of lettuce and chard in four treatments from every day of data collection, asterisks denote α<.05 on single date of data collection.

Stomatal Conductance						
Date of Collection	4/22/21	4/27/21	4/29/21	5/4/21	5/20/21	5/25/21
Temperature (C)	11.7	18.1	30.1	26.2	17.4	16.8
Lettuce Monocrop	0.278	*0.299	0.3	0.381	0.217	0.328
Lettuce Rec. Den. Intercrop	0.274	*0.266	0.3	0.403	0.193	0.191
Lettuce High-Den. Intercrop	0.274	*0.344	0.305	0.317	0.196	0.169
Chard Monocrop	*0.13	0.093	0.124	0.131	0.141	0.213
Chard Rec. Den. Intercrop	*0.227	0.279	0.697	0.312	0.141	0.201

Chard High-Den. Intercrop	*0.159	0.46	0.11	0.143	0.127	0.186

Table 3. Stomatal conductance and chlorophyll fluorescence average measurements from all dates of data collection.

Average Stomatal Conductance and Chlorophyll Fluorescence		
Agroecosystem	Stomatal Conductance	Chlorophyll Fluorescence
Lettuce Monocrop	0.301	0.615
Lettuce Rec. Den. Intercrop	0.271	0.599
Lettuce High-Den. Intercrop	0.268	0.638
Chard Monocrop	0.139	0.668
Chard Rec. Den. Intercrop	0.310	0.641
Chard High-Den. Intercrop	0.198	0.676

4.5 Root Measurements

The intercrops produced longer roots on average for the lettuce when compared to the monocrop. The greatest length in lettuce roots was seen in the recommended density intercrop and the shortest average lettuce roots were within the monocrop treatment (Figure 7). The monocrop performed the best in terms of average root width and root mass for the lettuce crop. The greatest mean root width for the lettuce was within the monocrop treatment, however, the average width across the four treatments only varied by .255 centimeters. The recommended density had the smallest average root width of any treatment for the lettuce. The greatest average root mass for the lettuce was found in the monocrop treatment at 27.09 grams. The recommended density was slightly less mass at 25.95 grams and the high-density intercrop was the lightest mass at 24.41 grams. The differences in root length, width and mass not significantly impacted by the treatments for the lettuce crop.

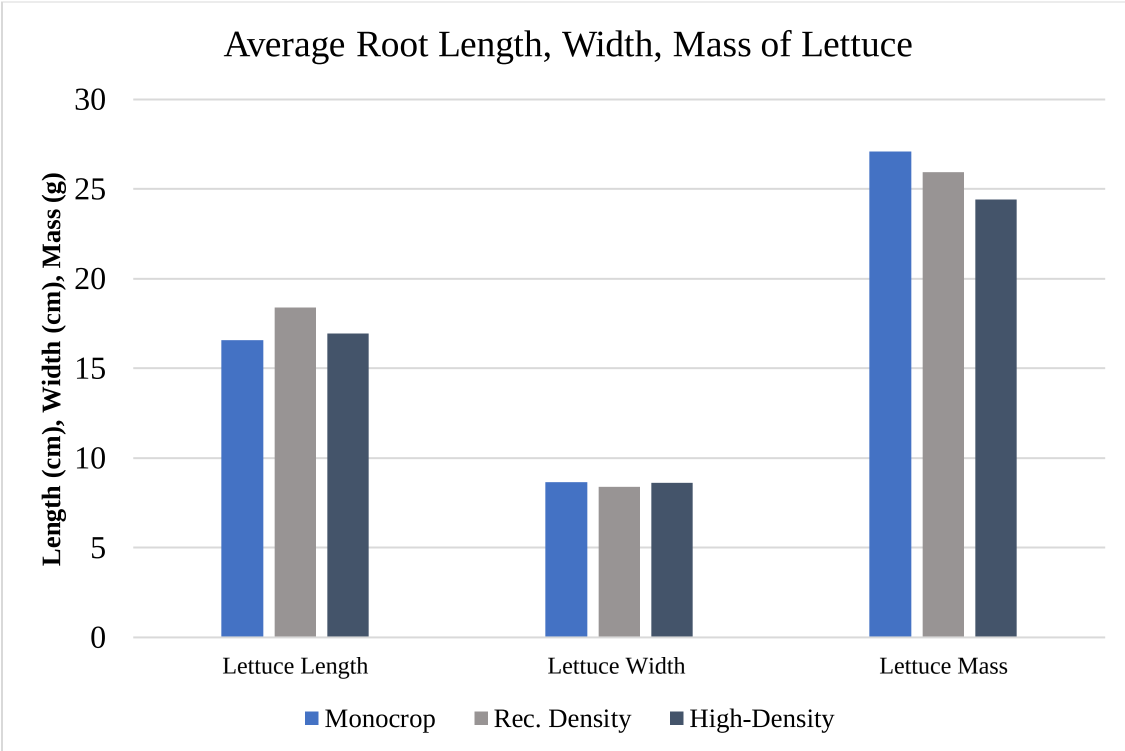

Figure 7. The mean root measurements of the lettuce in the treatments

Similarly to the lettuce, the mean greatest root length for chard were observed in the recommended density treatment (Figure 8). However, the monocrop produced roots that were very close to the length of the recommended density intercrop, only differing by .61 centimeters, and the high-density intercrop produced the shortest average roots, at 17.89 centimeters.

The chard's average root width was the greatest in the monocrop treatment. The lowest average root width was observed in the high-density intercrop for chard. The greatest root mass for the chard was found in the recommended density intercrop as it was 3.54 grams heavier than the monocrop and 5.26 grams heavier than the high-density intercrop. There were no significant differences found between the length, width and mass of the chard roots in the different treatments.

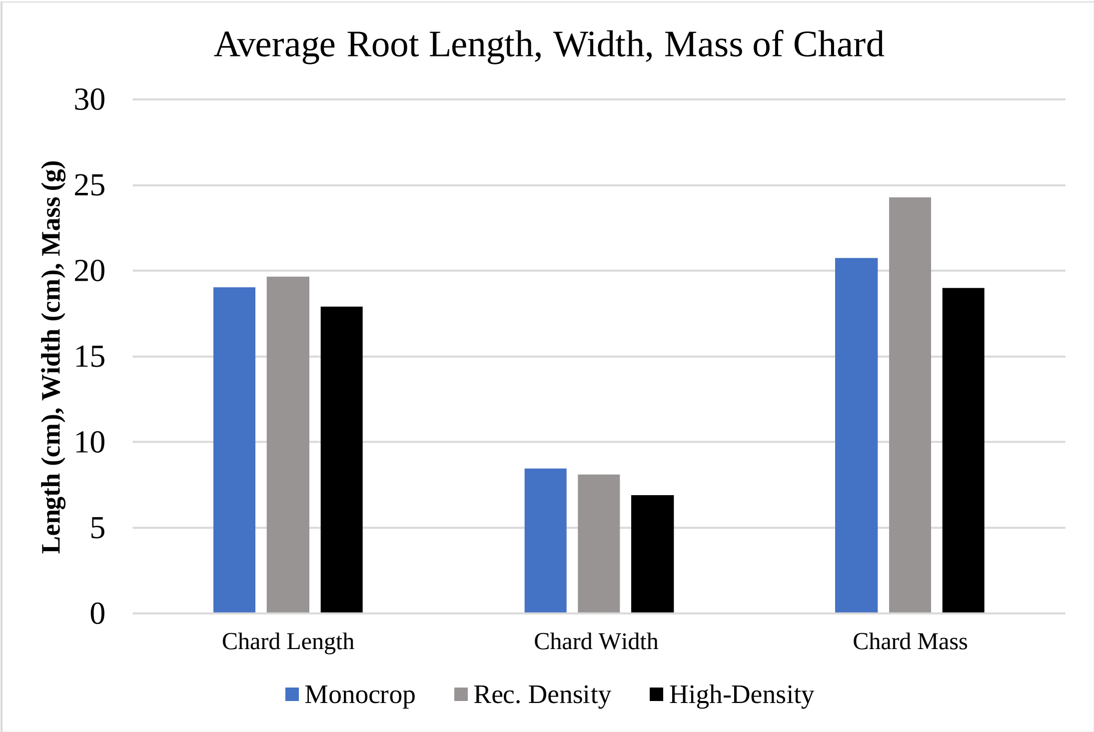

Figure 8. The average root measurements of the chard in the treatments

4.6 Soil Moisture and Temperature

Over time, the soil throughout all of the treatments experienced a decrease in soil moisture and an increase in soil temperature, showing an indirect relationship. In the beginning of the crop cultivation, the monocrops reported the lower soil temperatures than the intercrops (Figure 9). Although, the soil temperature across all of the treatments had little variation, with a range of .29 degrees Celsius. As the crops reached maturity, the intercrops were more successful in preventing the soil from reaching high heat. Towards the end of the experiment, both the chard and lettuce monocrops reported greater soil temperature than the intercrops. The gap between the lowest temperature and the highest temperature also widened. The lowest soil temperature was found in the recommended density treatment. The greatest change in soil temperature between the beginning and end of the crop growth was found in the chard monocrop, which increased by 9.09 degrees Celsius. The soil temperature was not significantly impacted by the treatments for either crop.

The soil moisture in the beginning of the crops' growing cycle was the highest in the recommended density intercrop and the lowest in the chard monocrop. Both intercrops reported greater average soil moisture than either of the monocrops. However, when the plants reached maturity, the greatest soil moisture was found in the lettuce monocrop and the lowest in the recommended density intercrop. The most drastic changes in soil moisture were in the recommended density intercrop, which decreased on the second date of data collection by 8.14. The soil moisture was not significantly affected by the treatments.

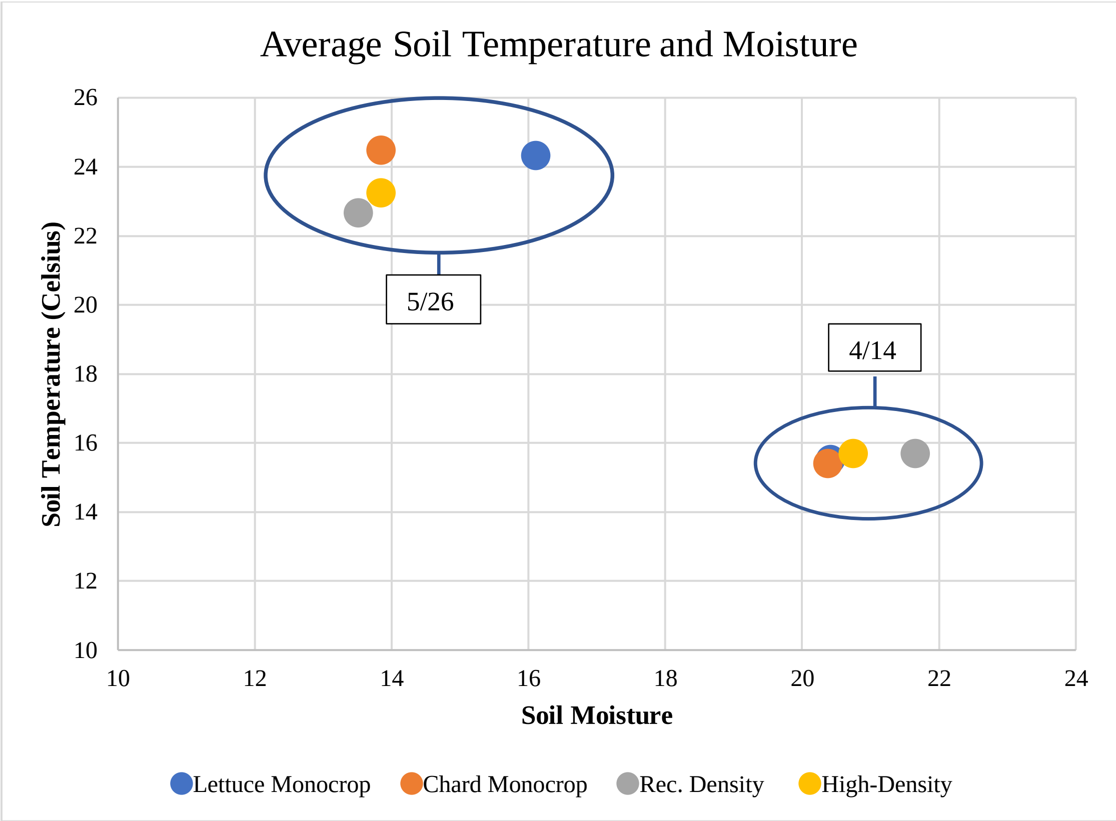

Figure 9. Scatterplot of average temperature and moisture content of the soil within each of the treatments, showing an indirect relationship between soil moisture and temperature

4.7 Yield

Both intercrop treatments overyielded based off of the total harvest. The greatest yield came from the high-density intercrop which provided a total yield of 64,682 grams (Figure 10). The high-density intercrop produced an average yield of 8,085.3 grams per bed. The recommended density intercrop produced an average of 7,862.8 grams of marketable harvest per raised bed and a total yield of 62,899 grams. The lettuce monocrop harvested an average of 6529.1 grams per beds and a total harvest of 52,233 grams. The chard monocrop yielded an average of 7342.8 grams per bed and a total yield of 58,742 grams. There is no significant difference among the average yield across the treatments for either crop.

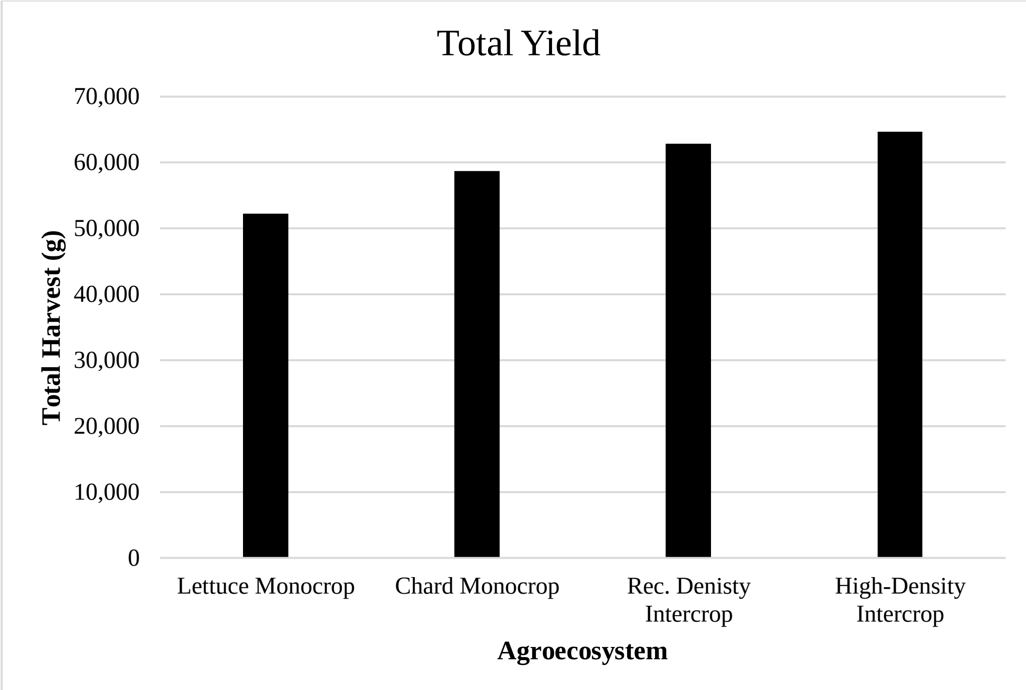

Figure 10. The total yield from accumulated harvest throughout the growing period

4.8 Land Equivalent Ratio

The LER results indicate that both of the intercrops used the land more efficiently than the monocrops. Both the recommended and high-density intercrops had LERs that are greater than 1, which indicate that more land would need to be used in a monocropping system to provide the same yield as the intercrops (Table 4). A monocrop would need 19% more land to produce the same yield as the recommended density intercrop and 26% more land to produce the same yield as the high-density intercrop.

Table 4. The LER of the recommended density and high-density intercrops.

Land Equivalent Ratio	
Treatment	LER
Recommended Density Intercrop	1.19
High-Density Intercrop	1.26

The results of the partial LER represent how much each species contributed to the total LER, as the total LER does not indicate if one species heavily overyielded to create a LER over 1. In the recommended density intercrop treatment, the chard had a higher partial LER than the lettuce, showing that it was the more successful crop in this arrangement (Table 5). In the high-density intercrop, the lettuce has a higher partial LER than the chard and contributed greater to the total LER.

Table 5. The partial LER of the lettuce and chard in the recommended and high-density intercrops.

Partial Land Equivalent Ratio	
Crop and Treatment	Partial LER
Lettuce Rec. Density	0.58
Lettuce High-Density	0.67
Chard Rec. Density	0.61
Chard High-Density	0.58

4.9 Economics

Both intercrops provided a greater economic value from the total harvest than either of the monocrops (Figure 11). The greatest economic value was in the high-density intercrop. Within this treatment, the total harvest was valued at $638.08. On average, each bed with the high-density intercrop treatment was valued at $79.75 for the total harvest it provided. The recommended density intercrop provided the second highest value harvest of $615.50. Each bed within this treatment averaged a value of $76.95.

The chard monocrop provided the lowest economic return out of any treatment tested. The chard monocrop's total harvest was valued at $517.55 and each bed averaged a value of $64.68. The harvest from the lettuce monocrop had a slightly greater value than the chard monocrop. The total harvest from the lettuce monocrop treatment was worth $575.25 and an average of $71.90 per bed. While treatments provided different values based off of the total marketable yields, economic value was not significantly affected by the treatment the crops received.

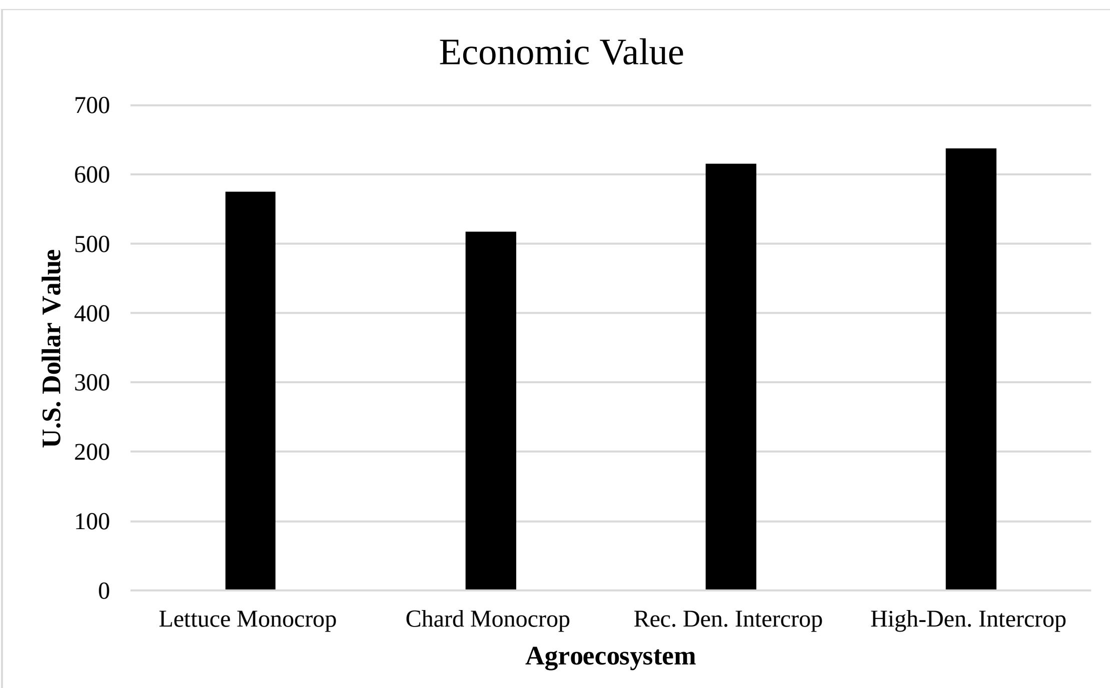

Figure 11. The economic value produced by the total yield harvested throughout the growing cycle

4.10 MANOVA Results

The results from the MANOVA test displayed that crop height at the end of the growing period significantly (p=0.009) affected the yields of the crops throughout different treatments (Table 6). The soil moisture once the crops had reached maturity were also a significant variable (p=0.027) that impacted the yields of the crops. Therefore, soil moisture and plant height were the most important independent variables impacting the amount of total yield.

Table 6. Level of statistical significance that independent variables had on effecting the yields of the crops in four treatments provided by a MANOVA test at $\alpha<.05$.

MANOVA Test Results	
Independent Variable	Significance in Affecting Yield (P-Value)
Herbivory (4/21)	0.933027
Herbivory (5/26)	0.682499
Height (4/21)	0.259071
Height (5/26)	0.009706
Soil Moisture (4/14)	0.177273
Soil Moisture (5/26)	0.027110
Soil Temperature (4/14)	0.912069
Soil Temperature (5/26)	0.907196
Root Width	0.801416
Root Length	0.344064
Root Mass	0.835942

5. DISCUSSION

This work was conducted to investigate if intercropped vegetable arrangements at recommended and heightened densities can be more environmentally resourceful, productive, and profitable than monocultures at recommended densities. Specifically, the research was centered around lettuce and chard grown in monocrops and intercrops at the recommended density of 6”, and intercrops at a heightened density of 4”. The crops within these treatments were tested to determine which arrangement was most beneficial for their growth, yield and economic return. The findings from this research provide a feasible manner in which these crops species can be cultivated in intercrops, which can be implemented on a larger scale. Using intercropping as a new form of vegetable agriculture in California would benefit the natural ecosystems and lead to less devastating environmental impacts than monocultures (Glaze-Corcoran et al., 2020). The results of this work show higher economic value, greater land conservation and yields when lettuce and chard are planted in intercropped arrangements than monocropped.

The yield results of both crops support the hypothesis that arranging these species in intercrops leads to overyielding. The high-density intercrop provided 12,000 grams more of harvest than the lettuce monocrop and 5,941 grams of yield than the chard monocrop. This is notable as even when there is a greater number of plants in a space, intercrops allow for less competition which leads to greater yields. The recommended density intercrop also provided a larger yield. Both intercrops overyielding lead to greater gross revenue for the total yields than the monocrop plots, which shows how this farming method can be economically beneficial to farmers.

Generally, the lettuce performed better in the high-density intercrop and the chard was most productive in the recommended density intercrop. As reflected in the total LERs, both crops overperformed in the intercrops. The partial LERs show that the lettuce had higher productivity in the high-density intercrop and the chard was superior in the recommended density intercrop. The overperformance of the chard in the recommended density intercrop could be due to the greater root length and mass found in this treatment, which could indicate greater water uptake which results in higher photosynthesis efficiency and crop productivity (Jackson et al., 2000). Patterns with stomatal conductance of the chard may have led to its high total yield in the recommended density intercrop. On each day of measurement, the chard had the highest stomatal conductance rates in the recommended density intercrop treatment. Greater levels of stomatal conductance indicated lower plant stress and could have contributed to its productivity success (González et al., 1999). The chlorophyll fluorescence of both crops was the highest in the high-density intercrop. The lettuce had a greater difference in chlorophyll fluorescence between the high-density intercrop and monoculture. This high level of chlorophyll fluorescence in the lettuce reflects low plant stress and likely assisted to its productivity of the lettuce in the high-density intercrop (Maxwell & Johnson, 2000). If this experiment were to be repeated, I would recommend cultivating plants that are harvested only once, not throughout the growing cycle. Harvesting the crops could have created stresses that lowered the photosynthetic efficiency of the crops.

The hypothesis that the intercrops would be more environmentally positive than the monocrops was supported by the outcomes of the LER calculation. The LER showed that greater land conservancy is reached when the crops are in the recommended and high-density intercrop arrangement than monocropped. By cultivating these crops in an intercrop arrangement, less land would have to transition from its natural ecosystem to agricultural land, which would support biodiversity. This hypothesis was also supported by the results of the soil temperature measurements. Once the plants had reached maturity, the lowest soil temperatures were found in the intercrop treatments. The recommended density soil temperature was approximately 2 degrees Celsius cooler than the monocrops. However, the soil moisture for the lettuce crops was negatively impacted by being in the intercrop design. The lettuce monocrop was able to retain greater soil moisture than the intercrops and the chard intercrop had comparable soil moisture to the intercrops. This indicates that the chard was more competitive with water sharing than the lettuce. The soil moisture of the chard was very similar to that of both intercrops, which is notable for the high-density intercrop that performed comparable water sharing while cultivating a third more plants than the monocrop treatments. The results from the percent herbivory method did not support this hypothesis as both crops experienced less pest interaction when planted in monocrops. Further research should be conducted to determine how to lower herbivory of the crops within intercrops. The time at which the plants are cultivated could be differentiated, as the lettuce attracted more pests in the beginning of the growth cycle and the chard had more pest interaction once reaching maturity. The harvests could have greater quality in terms of herbivory if the lettuce was planted before the chard and the chard was added into the system after the lettuce has a few weeks to mature. If this research was conducted, the lettuce should be harvested prior to the chard reaching full maturity to reduce herbivory impacts. I would also recommend studying these treatments in more isolated areas. In the design of this experiment, the treatments were in close proximity of each other. By having the treatments further apart, or with a buffer in between, the monocrops would be truly isolated and not impacted by having other crop species nearby.

In terms of plant productivity, beneficial patterns can be found in the rooting system of the chard within the recommended density intercrop treatment. The chard produced stronger root structures which are reflected by the heightened length and mass of the roots within the recommended density intercrop treatment. Deeper roots are beneficial to water uptake and resilience of the chard (González et al., 1999). The results of the root measurements did not reflect any patterns for the lettuce. The intercropping systems could have been more productive if a lettuce varietal that has shallower roots and a chard varietal that has deeper roots were cultivated. This would allow for the chard roots to extend deeper and the lettuce roots to grow wider, which could allow for lessened competition for below-ground space and lead to greater yields.

Many of the findings from this study are aligned with results from other research that that analyzed crops in monoculture and intercrop arrangements. Other research has found that it is more economically positive to grow crops in an intercrop, as crops benefit off of interspecies interactions and intercrops are meant to be more self-sustaining, therefore, farmers are able to save money as less management is required (Liang et al., 2020; Tonye & Titi-Nwel, 1995). This work came to the same conclusions as the intercrops provided a greater economic return from higher yields than the monocrops. Many studies completed on diversified crop systems result in higher quality yields than that of sole crops and other research comments on the positive biological control aspects of intercropping (Pardon et al., 2018, Brennan, 2016). Within this study, pest interaction with the crops was not positively affected by the monocropping arrangements. Within this experiment, the percent herbivory was greater in the intercrops, and therefore, the quality of the yields in the intercrops was diminished by heightened herbivory.

The results from the MANOVA test analyzing the impact that variables had on the yield showed that soil moisture and plant height at the end of the growth period had significant impacts on the yields of the crops throughout all treatments. This impact is reflected in the soil moisture of the lettuce monocrop, as it was higher than any of the other treatments. The heightened soil moisture indicates that there was less competition for water resources in the lettuce monocrop than any other treatment. This is due to the lettuce monocrop having less productivity, as it was the lowest yielding treatment. While there is an ecologic benefit to having soils with greater moisture retention, the higher soil moisture reflects the low yields of the lettuce monocrop. The impacts of plant height on yield can also be observed in the results of the lettuce crop. When plant height was recorded once the crops had reached maturity, the height was greater for the lettuce in the intercrop, which assisted in providing greater yields. The plant height for the chard was decreased in the intercrop treatments, which could have led to the lettuce receiving greater amounts of sunlight due to reduced shading and contributed to greater yields of the lettuce in the intercrops. If this research were to be repeated, I would recommend planted the crops at differentiated time periods to give the lettuce the ability to grow taller. Once the chard reached maturity, it began to shade the lettuce. By planting the lettuce before the chard, it could reach greater heights from increased solar capture, and lead to even greater yields than what was observed in this experiment.

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