INFLUENCE OF SOIL TYPE, FERTILIZER, AND MULCH AMENDMENTS IN CONTAINERIZED POLYCULTURE

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ABSTRACT

There are many avenues to address global food supply and global food production increasing food security for individuals and communities. Though corporate agriculture provides the largest percentage of global sustenance through grain monocultures, small-scale, subsistence, intercropping production is another means of direct-to-consumer horticultural supply for additional food security. Due to supply chain disruptions, inferior infrastructure, economic lack, and inaccessible land and/or agricultural equipment, large-scale production is not always feasible in impoverished communities where food security is greatest. This research determines the feasibility of growing "The Three Sisters" polyculture in containerized production as well as fertilizer and mulch amendment recommendations per container for optimal combined harvest weights. With the production model presented in this research, one container would supply an individual with one day of sufficient calories and two days protein, making container polyculture production a feasible means of attaining food security when used as a supplementary production for adequate nutrition.

Key Words

containerized vegetable production, The Three Sisters, *Cucurbita pepo*, *Zea mays* var. rugosa, *Phaseolus vulgaris*

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INTRODUCTION

In 1970, Norman Borlaug received the Nobel Peace Prize for his decades-long research and dedication to end world hunger through improved wheat varieties and increased annual yields (Hesser, 2006). In his acceptance speech, Borlaug highlighted the collaboration of various agencies, scientific research, and longevity needed to truly end global hunger and malnutrition. Fifty years later, we are still fighting the same battle to end hunger.

In 2020, the United Nations Children's Fund, the World Health Organization, and the World Bank provided joint research on global hunger and malnutrition (UNICEF, 2020). The released data estimated that 144.0 million children under age 5 suffered from stunting, a condition where physical and cognitive development never reaches full potential due to malnutrition. Though largely recognized in underweight children, this condition can also occur in children that are overweight but lack key nutritional components in their diets. As malnutrition persists, the physical and cognitive condition deteriorates resulting in life threatening starvation, also called wasting. This condition is highest per capita in lower to middle class income countries in Africa and Asia where subsistence farming is the main income (Sibhatu and Qaim, 2017). In 2020, stunting and wasting increased globally to nearly one in three people due to the COVID-19 pandemic, an increase of almost 320 million people in just one year (FAO, 2021). This figure is set to increase in 2022 with food prices increasing 21 percent (FAO, 2022).

Malnourishment largely stems from economic poverty due to an inadequate food source or nutritional poverty due to inadequate access to nutritionally and calorically proficient food. Food security is defined as the ability for an individual or family to source or produce adequate amounts of food satisfactory for living (UNICEF, 2020). It has been recorded since the days of famine in ancient history, as early as 2700 BC (Davidovits, 1988). The agricultural community is often tasked not only with the science of horticulture and agronomic crop production but also scaling such production to a degree that it could potentially feed the world and eliminate food insecurity globally. Norman Bourlough represented a large-scale agricultural approach to ending world hunger. Large-scale conventional agriculture with international trade is one answer for global hunger. Due to supply chain disruptions, inferior infrastructure, economic lack, and inaccessibility to land and/or agricultural equipment, large-scale production is not always feasible in impoverished communities where food security is most needed. Therefore, opportunities exist to feed individuals or defined groups of people through small, economically, and physically efficient crop production systems particularly when access to productive acreage is absent.

Van Cotthem (2016) suggested that small-scale vegetable production can prove massively beneficial to food insecure peoples. Based in Africa, his research highlights the use of plasticulture, horticulture production utilizing plastic bags and containers, to grow food in community-based school settings, a model also replicable in family or community atmospheres. Small-scale food production systems can be utilized in a variety of economically efficient containers and sacks where land is unavailable or limited and/or the soil is degraded. Small-scale horticulture production systems decrease the need for large economic investments typically used in conventional farming for land, machines, and seeds to increase scalable agricultural production based upon need, offering nutritional and caloric value otherwise unavailable to undernourished individuals and communities. It also has the potential to increase sustainability agriculturally through biodiversity and crop rotation (Sibhatu and Qaim, 2017) and nutritionally by increasing the variety of essential vitamins, minerals, protein, and calories. This increases the health of the soil and the producer (Reyes-Garcia and Benuei, 2019).

This research seeks to determine the effectiveness of utilizing "The Three Sisters" polyculture in containerized production for optimal yield per container and the associated calculated caloric value. Evaluation of container soil type, soil amendment type, and fertilizer type was used to determine the optimal combination for total harvest weight per container as a foundation for establishing a small, subsistence agricultural production model for supplemental nutritional value to increase food security.

1. LITERATURE REVIEW

1.1. Polycultures

It is estimated that two-thirds of the population within low-economic countries rely on subsistence farming, a number that can increase to 90 percent based upon location (FOA, 2015). Subsistence farming consists of crop production on less than two hectares, or four acres, of land largely for the consumption of the producer. Any harvest beyond that needed for consumption is sold in small markets as income. Most subsistence farmers grow one crop, typically grain. It could be argued, however, that intercropping could make more efficient use of the small land area and increase the nutritional value of the harvest.

Intercropping is an agricultural strategy in which two or more crops, a polyculture, are interplanted to grow side by side in the same or overlapping seasons but not necessarily planted or harvested simultaneously (Fung et al., 2019). Intercropping can utilize same-row or between-row planting or, in the case of this research, the same container. Plants utilized in this system are often chosen based upon plant interaction and overall planting goals. The main benefit of polycultures is an increase in vegetative biodiversity and improvement in soil quality (Martinez, 2007). Intercropping may also suppress weeds and pests (Liebman and Dyck, 1993) and decrease potential diseases (Midega et al., 2014). Vining crops and low-lying plants are often used as ground cover in intercropping systems leading to greater rainwater infiltration (Blaise et al., 2021), increased microbial and earthworm activity, optimized soil temperatures, and decreased evaporation rates (Nyawade et al., 2019). For subsistence farmers, polycultures also improve the overall health of the producer through a more diverse diet (Reyes-Garcia, 2019). Polycultures have the potential to withstand climatic, pest, and disease events better than monocultures but the interplanted horticulture crops should be selected carefully to avoid competition for space and fertilization needs (Martinez, 2007).

1.2. "The Three Sisters"

This research specifically looks at "The Three Sisters" Polyculture, a traditional intercropped system of the Native American Iroquois and Senenca tribes where maize (*Zea mays*), bean (*Phaseolus* sp.), and squash (*Cucurbita pepo*) were grown simultaneously creating a sense of agricultural symbiosis portrayed as agricultural harmony (Lewandowski, 1987 and Mt. Pleasant, 2006). The three crops serve three separate functions in the polyculture taking "advantage of their differing and complementary growth habits, plant architectures, agronomic characteristics, and food values" (Mt. Pleasant, 2016).

Evidence for "The Three Sisters" polyculture originates in Central and South America (Dillehay et al., 2007) eventually arriving in the North American Southwest, Plains, and East (Adair, 2003). Maize and beans have been grown together since beans appeared in the archaeological record (Landon, 2008). It has been suggested that "The Three Sisters" were originally grown in monocultures (Hart, 2008) before being intercropped as a polyculture around 700 BC requiring less time and labor (Parker, 1910 and Mt. Pleasant, 2016). After the addition of squash, the polyculture is consistently recorded complete with all three crops (Mt. Pleasant, 2006). Maize, bean, and squash were thought to be guarded by three inseparable spirits, leaving the plants incapable of surviving in monocultures (Parker, 1910).

Traditionally, "The Three Sisters" were grown in uncultivated fields in mounded sections (Mt. Pleasant, 2016). Maize and beans were interplanted in the center of each mound surrounded by vining squash. As the maize grew, the vining beans would climb the maize stalk for support. Squash would be added around the perimeter of the system to provide ground cover, reducing weeds and soil temperatures (Hart, 2008). The entire agricultural system would be created of multiple mounds grown and harvested simultaneously. Planting on mounds may have increased soil drainage and improved root growth due to decreased soil compaction (Mt. Pleasant and Burt, 2010). In his research, Martinez (2007) reported that "The Three Sisters" had an increased soil temperature during weeks 0-2, increased germination, and decreased soil temperature in weeks 4-10, aiding in weed suppression and increased soil moisture. As a polyculture, the "three vegetables appear to symbiotically benefit each other, thus reducing the need for fertilizers, herbicides, pesticides, irrigation, and weeding" (Martinez, 2007). By mimicking natural plant communities, polycultures, such as "The Three Sisters", can also be more stable than monocultures and be more efficient at using natural resources such as light, nutrients, and water (Hart, 2008). After harvest, material not harvested from "The Three Sisters" was left concentrated on the mounds to decompose, increasing organic matter and soil fertility for subsequent crops (Mt. Pleasant and Burt, 2010).

Parker (1910) described more than a dozen varieties of maize and similar numbers of bean varieties, as well as many types of cucurbits and squashes, including *Cucurbita moschata*, *Cucurbita maxima*, *Cucumis melo*, and *Cucumis sativus* grown in Iroquois communities. The "The Three Sisters" are also pivotal in early American history as it was taught in early English settlements by Native American tribes (Parker, 1910). Reintroducing this system into modern subsistence agriculture settings, "may be an effective strategy in the development of sustainable and productive practices for farmers today" (Martinez, 2007).

"The Three Sisters" may also be capable of stemming the effects of food insecurity. Utilizing maize, bean, and squash as diet staples can provide basic energy and protein requirements. Mt. Pleasant (2016) reported that "The Three Sisters" polyculture could supply the energy requirements of approximately 13 people per hectare per year and the protein requirements of approximately 15 people per hectare per year. This results in two to four times more energy and protein when grown as a polyculture when compared to monocultures of each crop. The reintroduction and incorporation of "The Three Sisters" into both the agricultural practice and diet of subsistence farmers may help reduce the consequences of food insecurity, malnutrition and wasting, while also providing a sustainable, economic, and environmentally beneficial farming method.

1.2.1. Maize

The Iroquois nation called maize "our life" or "it sustains us" (Parker, 1910). Today, maize and other grains such as rice, barley, and wheat envelope the vast majority of subsistence farming crops (FAO, 2015). Most subsistence farmers rely on cereal grain (wheat, rice, or maize), combined with a legume (bean, lentil, or pea), to provide the bulk their dietary needs when harvested in the dry form. Maize is valuable because it produces large amounts of energy, modest amounts of protein, and can be stored over a long period of time (Mt. Pleasant, 2016).

As a member of "The Three Sisters", maize competes well against weeds and acts as climbing poles for bean vines. Mt. Pleasant and Burt (2010) compared "The Three Sisters" as a polyculture to monocultures of the three crops and found maize yields were not affected regardless of planting system. Though not an excellent source of protein alone, maize can be combined to create a complete protein when mixed at a ratio of 30 parts beans to 70 parts maize, establishing a solid nutritionally and calorically proficient dietary base (FAO, 1992).

1.2.2. Beans

Beans are another crop typically mixed in intercropping systems due to their ability to fix soil nitrogen through symbiotic relationships with soil bacteria and convert it into a form that is usable by the plant, reducing the need for continuous fertilizer use (Bernai et al., 2004 and Hanming et al., 2011). This ability to provide a nitrogen source to other crops potentially reduces the need for additional nitrogen fertilizer in certain intercropping systems and is beneficial in “The Three Sisters” polyculture due to the high nitrogen need of maize (Martinez, 2007). Beans also provide a good source of protein and high caloric value that is beneficial to the producer (Mt. Pleasant, 2016).

In Iroquois tradition, vining bean varieties were planted around the outside of the maize once the maize reached four to six inches in height (Mt. Pleasant, 2006). The beans would then climb the maize stalks utilizing it as the pole. Beans would be harvested once dry simultaneously with the dry maize and stored for winter (Parker, 1910).

Bean yields are reduced when grown in a polyculture compared to a bean monoculture due to competition for aerial space and light (Santalla, 2001 andMt. Pleasant and Burt, 2010). Decreased bean yield in a polyculture is a necessary trade off when comparing the increased nutritional value of adding beans to maize as yields of maize are not decreased and maize remains more economically efficient, and the combination produces a higher quality protein (Mt. Pleasant and Burt, 2010). Beans contain as high as twice as much protein per unit compared to maize or pumpkin crops, so the loss of yield does not cause the overall nutritional value of the polyculture to decrease (Mt. Pleasant, 2016). Comparing bush bean yields, Santalla (2001) found yields higher when beans were intercropped with sweet maize compared to field maize, an option available to today's producers that was not available to the original creators of "The Three Sisters". Intercropping using beans is crucial for sustenance farmers who feed themselves from their crop (FAO, 2015).

1.2.3. Squash

Squash utilized in "The Three Sisters" consisted of any cucurbit variety with the potential of extended winter storage (Parker, 1910). Large leaves covered the ground, reducing evaporation, decreasing soil temperatures and weed germination, and aided in soil moisture retention (Hart, 2008). Heritage varieties may have also contained spines along the vines discouraging predator and pest presence (Hill, 2020). After harvest, decomposing leaves increase soil organic matter and act as a mulch (Hart, 2008).

Winter squash is the most nutritionally dense crop in "The Three Sisters". Pumpkin, especially, can increase the quality of protein when combined with maize and beans and contains large amounts of Vitamin A (Mt. Pleasant, 2016). Pumpkin flesh and seeds also have a high caloric value. Walters (2006) found that 1 kg pumpkin (fresh field weight) yielded 13 grams of dry seed. Though there was no historical record of Iroquois specifically eating seeds of squash, there was a historical record of them eating the seeds of other crops (Parker, 1910). Therefore, the essential amounts of amino acids and dietary fiber found in pumpkin seeds should be assessed when calculating the nutrition value of pumpkins (Mt. Pleasant, 2016).

1.3. Nutritional Value of Fresh Picked "The Three Sisters"

Differing from traditional "The Three Sisters" production methods, this research examined the immature, fresh-harvested value of "The Three Sisters" as opposed to mature, dry harvested value. Utilizing immature, fresh varieties decreases the overall nutritional value of "The Three Sisters", as a large portion of production weight is water weight (Mt. Pleasant, 2016). Fresh-picked crops, however, do not warrant additional economic means or space usage needed for long-term storage, such as canning, freezing, or drying.

Daily Value percentages are recommendations for nutrient amounts needed for an average adult to stay healthy. The Daily Value percentages for yellow sweet maize, pole green beans, winter squash, and pumpkin seeds can be found online at the U.S. Food and Drug Administration website (FDA, 2020). Utilizing the USDA's Food Data Central (2019), nutritional values of fresh-picked yellow sweet maize, green string beans, winter squash and seeds were compared to the daily value of an average adult consuming 100 grams of each vegetable and seeds per day (Table 1). Per serving, "The Three Sisters" provide greater than 100% daily value of Magnesium and Phosphorus and more than 50% daily value of protein, fat, Iron, and Vitamin A. Even when using fresh-picked varieties, "The Three Sisters" remain a source of high-quality calories, fat, and protein while also providing needed essential nutrients.

Table 1. Nutritional Values for 100g fresh, raw vegetables grown in "The Three Sisters" polyculture

	maize (sweet, yellow)	green beans (string)	winter squash	Pumpkin seed	Total	Comparative Daily Values*	%Daily Value
Energy (kcal)	86	31	26	574	717	2000	71.70%
Protein (g)	3.27	1.83	1	29.8	35.9	50	143.60%
Fat (g)	1.35	0.22	0.1	49	50.67	78	129.92%
Carbohydrates (g)	18.7	6.97	6.5	14.7	46.87	275	34.09%
Fiber (g)	2	2.7	0.5	6.5	11.7	28	83.57%
Sugar (g)	6.26	3.26	2.76	1.29	13.57	50	54.28%
Calcium (mg)	2	37	21	52	112	1300	17.23%
Iron (mg)	0.52	1.03	0.8	8.07	10.42	18	115.78%
Magnesium (mg)	37	25	12	550	624	420	297.14%
Phosphorus (mg)	89	38	44	1170	1341	1250	214.56%
Potassium (mg)	270	211	340	788	1609	4700	68.47%
Sodium (mg)	15	6	1	18	40	2300	3.48%
Vitamin A (µg)	9	35	426	0	470	900	104.44%
Vitamin C(mg)	6.8	12.2	9	1.8	29.8	90	66.22%
Folate (µg)	42	33	16	57	148	400	74.00%
Vitamin K (µg)	0.3	43	1.1	4.5	48.9	120	81.50%

1.4. Containerized Production

Horticulture production in containers is not a modern technique but has grown steadily in popularity in recent years (Mason, 2008). Containers improve soil drainage and increase the soil temperature to facilitate earlier seed germination (Martinez, 2007). Additional benefits of containerized production include reduction of physical and mechanical exertion, scheduled and calculated irrigation, weed suppression, increased square foot usage, and decreased economic input. Containerized production is particularly important for those without access to tillable land, those who plant on degraded soils, or those that lack the economic input necessary for equipment or fuel utilized in a larger scale commercial vegetable or grain production, by creating the opportunity to transform food desserts (Holmer, 2002).

In containerized production, soil mediums and fertilizer types are the primary concerns in management practices (Burnett et al., 2016). The length of the production cycle determines the fertilization method implemented. Due to the short-term nature of most fertilizers, multiple strategies and a combination of fertilizers can be utilized. Slow-release, or controlled-released, fertilizers can supply constant nutrients over time reducing the frequency of fertilizer application, nutrient loss due to leaching, and the overall cost of fertilizer (Mack et al., 2019). A diversified fertilization method is recommended to reduce nutrient loss (Burnett et al., 2016), as nutrient losses through leaching increases when large doses of slow-release fertilizer is top-dressed in a single application (Cox, 1993).

Soil in containers is elevated above the ground level, increasing the soil surface area in contact with the air which produces greater daytime and nighttime temperature fluctuations compared to in-ground soil temperature (Hanming, 2011). Therefore, containers maintain a slightly higher daytime soil temperature, potentially increasing overall crop yield, and a slightly lower nighttime soil temperature, potentially increasing plant carbohydrate production. Depending on the irrigation system, lower relative humidity rates during daytime hours often occurs, decreasing the injury potential from diseases. Hanming (2011) reported that utilizing container vertical space, such as the vining bean in "The Three Sisters," increased light intensity as well as improved plant dry weight and yield.

Soil amendments are an important consideration for production given the increased soil temperature and lower relative humidity in container production. Blending different ratios of amendments into container soil preserves large pore space and helps to maintain structural integrity (Bilderback et al., 2005). Common soil amendments include peat moss, coconut coir, perlite, and vermiculite. Ratio recommendations vary based upon purpose. Kim and Kim (2011) found soil percentage of 60% of total container volume best for crop production. Similarly, a 3:1 ratio soil to amendment was recommended for apple rootstock propagation (Kim et al., 2021). Van Cotthem (2016) recommended one-part soil, one-part peat or soilless substrate, one-part sand, and one-part slow-release fertilizer in plasticulture production. For nursery production, Bilderbeck and Fonteno (1987) recommended one-part peat to one-part vermiculite with one-gallon containers. When using a soilless substrate, adding 13% of clay soil into the substrate was shown to greatly increase water-holding capacity and plant productivity in containers (Carlile et al., 1988 and Owen, 2006). Further research is needed to determine which amendments and the soil to amendment ratio is best suited for containers larger than one gallon in volume. Specific research is also needed for containerized polyculture production.

Container size is a fundamental determinant of overall plant size and health (NeSmith and Duval, 1998). Cantiliffe (1993) reported that as container size increased plant leaf area, shoot biomass, and root biomass also increased. The reduction of container size directly impacts air and water holding capacity, media pore space, and aeration (Bilderback and Fonteno, 1987). In small containers, plant roots become restricted limiting root growth, plant-water relations, and nutrient uptake which in turn limits shoot growth, biomass accumulation, photosynthesis, leaf chlorophyll content, respiration, flowering, and yield (NeSmith and Duval, 1998). Research indicated that root restriction reduced the overall photosynthetic rate in bell pepper (NeSmith et. al., 1992) but only reduced the photosynthetic rate in summer squash with prolonged root reduction (NeSmith, 1993). The photosynthetic rate of soybeans was not affected by root restriction (Krizek et al., 1985), indicating that vegetables with smaller shoot diameter may be less affected by container size. Peterson et al. (1991a) showed that the flowering period of tomatoes was also reduced with increased root restriction, but NeSmith (1993) found the flowering period of summer squash was unaffected. This indicates that effectiveness of containerized production would be dependent on the horticulture crop(s) selected, the duration of use, and size of the container.

Additional considerations with containerized production include plant stress caused by above ground temperature fluctuations, increased topsoil and container evaporation rates, and rapid water drainage (Bilderback and Fonteno, 1987). Generally, plants grown in containers have a different root morphology than the same crop seeded in field production (NeSmith et al., 1992). Shallow root systems condensed in limited space predisposes plants to drought stress and competition for available oxygen (Peterson et al., 1991b). Due to the porous nature of container substrates, containerized crops are often irrigated daily (Mack, 2019). The frequency of irrigation is dependent on "seasonal and daily weather affecting evapotranspiration, container type and size, plant size, soilless substrate physical properties, growth rate, and species" (Bilderback et al., 2013). Precision irrigation systems have emerged as an efficient watering system to optimize time and water usage (Nikolaou et al., 2019). Lamack and Niemiera (1993) found that cyclic irrigation through the spray stake irrigation method increased the water application efficiency by 10% with multiple, lower quantity water applications compared to one-time applications in the same time period. Cyclic irrigation is also found to reduce nutrient loss through leachate, reducing the need for additional fertilizer applications (Bilderback et al., 2013).

Though scalable, most containerized production systems are small in aerial space with limited yield capacity compared to traditional commercial production methods. Wehner and Naegele (2018) found that determinant, monecious vegetables varieties moderately intercropped in large containers, such as the cucurbits in this research, perform better than indeterminant, dioecious varieties in containers. Utilizing horizontal and vertical space with both bush and vining plants maximizes the square footage of each container. This allows growers to produce multiple diverse, high-value crops, such as "The Three Sisters," as opposed to one or two mainstream agronomic crops, such as wheat or soybeans. Selection of crops used in polycultures depends upon area, climate zone, irrigation access, seasonal use, cultural preference, caloric need, and market demand. Crops for fresh eating and winter storage can be produced and interplanted within the same container, elongating the seasonal usage (Wehner and Naegele, 2018). Containerized production provides a moderately controlled environment in which irrigation needs, fertilizer needs, pest control, disease control, and to some extent temperature can be modified to meet the needs of the grower and the crops produced creating an agricultural method that is both economically and environmentally feasible as well as increasing the accessibility to nutrient dense foods.

2. MATERIALS AND METHODS

2.1. Container

Each experimental unit consisted of one container. The container used in this research was a standard, food-grade 5-gallon (19L) bucket, each filled with 23 kg or 50 pounds of soil. Buckets were selected for accessibility and frugality. All buckets were white in color to reduce heat retention and temperature fluctuation. Four ½ inch holes were drilled in the bottom of each bucket for drainage.

2.2. Experimental Plot

Research was conducted at two separate areas during the summer of 2020. Study A was located at Steadfast Acres Farm in Osakis, MN (lat. 45°52’19” N, long. 95°5’39”W). Study B was located at the North Dakota State University (NDSU) campus in Fargo, ND (lat. 46°87´59´N, long. 96°78´17´E). Each experiment was 50ft. x 35ft. in size, located in full sun and entirely covered in landscape fabric to suppress weeds and prevent root development underneath the buckets. Study A was also fenced to ensure vegetative security from local livestock and wildlife.

2.3. Selected Polyculture

Traditionally, “The Three Sisters” system encompassed maize and bean varieties that were dried on the stalk or vine, and all were harvested at the same time as the pumpkin for long term use and storage. Due to the decreased need for long term storage, this research focuses on varieties for fresh harvest and consumption. ‘Early Sunglow’ hybrid sweet maize (*Zea mays* var. rugosa) is a short season variety selected for its ability to grow well in containers and its higher germination rate over comparable varieties. It produces 1.22-to-1.37-meter stalks with multiple 15-to-8-cm ears per stalk. Organic ‘Early Sunglow’ hybrid sweet maize seed was purchased from Burpee Seeds (Warminster, Pennsylvania). ‘Kentucky Wonder’ pole bean is a prolific, short-day, self-pollinating variety with 18-to-23-cm pods which can be eaten fresh or stored. Organic ‘Kentucky Wonder’ pole bean seed was purchased from Burpee Seeds (Warminster, Pennsylvania). ‘New England’ pie pumpkin (*Cucurbita pepo*) is a small winter squash producing 2.27-to-3.18-kg fruit, selected for container size and fertilizer restrictions. This variety can be easily stored though not as hardy as other larger, cured pumpkin varieties. Organic ‘New England’ pie pumpkin seed was purchased from High Mowing Organic Seeds (Wolcott, Vermont).

2.4. Soil Media

The first experimental factor included three soil types (Fargo silty clay, Roliss loam, and topsoil). The Fargo silty clay soil, referred hereafter to as North Dakota Clay, was collected from North Dakota State University in Fargo, North Dakota (lat. 46°87´59´N, long. 96°78´17´E). The North Dakota clay consists of dark, moderate to fine subangular blocky structured and epiaquerts with poor drainage and slow permeability. The pre-planting soil test reported 0.454 kg nitrogen, 10 ppm phosphorus, and 180 ppm potassium in the sample. The Roliss loam soil, referred to hereafter as Minnesota loam, was collected from Steadfast Acres in Osakis, MN (lat. 45°52’19” N, long. 95°5’39”W). The Minnesota loam consists of dark, friable, poorly drained endoaquolls with weak to medium subangular blocky structure. The pre-planting soil test reported 41.73 kg nitrogen, 10 ppm phosphorus, and 150 ppm potassium in the sample. The store purchased Topsoil (Scott’s Premium, Marysville, Ohio), referred to hereafter as Topsoil, was purchased in Fargo, North Dakota. The pre-planting soil test reported 61.69 kg nitrogen, 119 ppm phosphorus, and 250 ppm potassium in the sample. Each soil type filled one third of the total experimental containers.

2.5. Soil Amendments

The second experimental factor consisted of four soil amendments (vermiculite, peat moss, a straw top layer, and no amendment) for increased soil moisture retention, increased water holding capacity, and decreased soil surface evaporation. FarmTek Vermiculite (North Field, Ohio), Premier Horticulture Organic Sphagnum Peat Moss (Quarkertown, Pennsylvania), and Rhino Seed EZ-Straw Seeding Mulch (Wayland, Michigan) were purchased as amendments.

Given the increased container volume and root biomass, this research used a ratio of 2:1 soil to vermiculite or peat moss so that 30% of the total bucket volume consisted of amendment. Vermiculite or peat moss was incorporated into the soil substrate prior to being placed inside the buckets. Additional vermiculite or peat moss was sprinkled on the top of respective buckets as a light soil topper after planting. Straw was not incorporated into the soil as a soil amendment. Buckets receiving the straw were covered with approximately a 13 mm thick layer after planting.

2.6. Fertilizer

The fertilizers used in this research represent three delivery types. Burpee's Organic Bone Meal Fertilizer (6-8-0) (Warminster, PA) is a fast-dissolving powder for quick nutrient release. Burpee's Organic All Purpose Granular Plant Food (4-4-4) is granular and provides nutrients over a three-month period. Jobe's fertilizer spikes for prolific flowering plants (10-10-4) from Easy Gardener, Inc. (Waco, TX) is a slow-release fertilizer providing nutrients over a 60-day period. The final treatment for this factor was a control with no additional fertilizer.

Fertilizer quantities were calculated utilizing the pre-planting soil tests. Each container would receive a total of 181.44 kg of nitrogen per acre for the season including the amount of nitrogen determined by the soil test (Table 2). A fertilization rate of 448.34 kg per hectare NPK was determined most satisfactory for one growing season in accordance with fertilizer recommendations for a four-month growing period in 35.56 cm pots containerized production (Conover, 1996).

Table 2. Calculated additional fertilizer per soil medium.

Soil Medium	Soil Test- kg N/hectare	Additional needed- kg/hectare	Additional needed- kg/container
North Dakota clay	58.28	390	0.0098
Minnesota Loam	103.12	345.22	0.0086
Topsoil	152.44	295.91	0.0074

Fertilizer amounts for each soil medium according to fertilizer type were calculated by multiplying the additional amount needed per container (Table 2) by the highest percentage of any single nutrient in the N-P-K package numbers (Table 3) to determine the highest amount of fertilizer available in each fertilizer type. Not having equal parts N-P-K, additional amendments were needed for the Burpee's Bone Meal (6-8-0) and Jobe's spikes (10-10-4) to reach 448.34 kg per hectare NPK.

Nitrogen Feather Meal (12-0-0) (Milwaukie, OR) was added to containers receiving Burpee's Bone Meal (6-8-0) to reach (8-8-0). To determine the amount of additional nitrogen needed, the value in the "Amount needed per container" column (Table 2) was divided by the percent phosphorus (8%) within the Burpee's Bone Meal (6-8-0) to calculate the total amount of fertilizer provided per container. This total was then multiplied by the percentage of nitrogen in the Burpee's Bone Meal (6-8-0) to find the amount of nitrogen per container. This number was further divided into kilograms of nitrogen per hectare. The nitrogen per hectare was then subtracted from the total nitrogen amount needed after soil testing (Table 2) to reveal the kilograms of nitrogen fertilizer still needed per hectare, which was then multiplied to find the grams of nitrogen fertilizer still needed per container (Table 3). This was divided by the percentage of additional nitrogen (12-0-0) to provide the grams of additional nitrogen fertilizer to be added with the Burpee's Bone Meal (6-8-0) (Table 4).

Table 3. Fertilizer available per container by soil medium in grams

Soil Medium-	Burpee's All Purpose (4-4-4)	Burpee's Bone Meal (6-8-0)	Jobe's Spikes (10-10-4)
North Dakota clay	98.66 g, 26.1 tsp	49.33g, 20.96 tsp	27.84 spikes
Minnesota Loam	87.32 grams or 23.1 tsp	43.66g, 18.46 tsp	24.64 spikes
Topsoil	74.84 grams or 19.8 tsp	37.42g, 15.87 tsp	21.12 spikes

Table 4. Additional nitrogen (12-0-0) amendment for Burpee's Bone Meal (6-8-0) fertilizer in grams per container

Soil Medium	Nitrogen (g)	Potassium (g)
North Dakota Clay	8.16 g	18.14 g
Minnesota loam	7.33g	15.88g
Topsoil	6.24 g	13.61g

Additional potassium (0-0-22) was also added in conjunction with the Burpee's Bone Meal (6-8-0) and the Jobe's spikes (10-10-4), to reach 8-8-8 NPK and 10-10-10 NPK respectively. For the Burpee's Bone Meal (6-8-0) fertilizer, the additional potassium fertilizer was calculated utilizing the "additional needed per container" (Table 2) because no potassium was available in the Burpee's Bone Meal (6-8-0) (Table 4). Calculations for additional K added to Jobe's Spikes (10-10-4) were done in the same manner as the previous nitrogen calculations (Table 5).

Table 5. Additional potassium amendments to Jobe's spikes (10-10-4).

North Dakota Clay	10.76g
Minnesota loam	9.53g
Topsoil	8.16g

*Weight of one stick = 1.42 grams

To reduce fertilizer loss, approximately half of each fertilizer type was incorporated into each container as a one-time, pre-plant dosage. Granular potassium and nitrogen Feather Meal was also added at this time. The final quantity of fertilizer was divided and distributed once weekly between week five and week 10 post planting (Table 6).

Table 6. Fertilizer schedule.

	PRE-pant	week 5	week 6	week 7	week 8	week 9	week 10
ND Soil Total	179 kg	44.8 kg	44.8 kg	44.8 kg	44.8 kg	44.8 kg	44.8 kg
Burpee's All Purpose (4-4-4) (tsp)	12.1	3	2	3	2	2	2
Burpee's Bone Meal (6-8-0) (tsp)	13.87	2.32	2.32	2.32	0	0	0
Jobe's spikes (10-10-4)	13.84	3	2	3	2	2	2
MN Soil Total	196 kg	42 kg	42 kg	42 kg	42 kg	42 kg	42 kg
Burpee's All Purpose (4-4-4) (tsp)	11.1	2	2	2	2	2	2
Burpee's Bone Meal (6-8-0) (tsp)	12.31	2.06	2.06	2.06	0	0	0
Jobe's spikes (10-10-4)	12.64	2	2	2	2	2	2
Topsoil Total	168 kg	42 kg	56 kg	42 kg	56 kg	42 kg	42 kg
Burpee's All Purpose (4-4-4) (tsp)	9.8	2	1	2	1	2	2
Burpee's Bone Meal (6-8-0) (tsp)	10.58	1.9	1.69	1.69	0	0	0
Jobe's spikes (10-10-4)	10.12	2	1	2	2	2	2

2.7. Container Construction

Container construction occurred a week prior to first planting. This allowed the soil to settle into the containers. Where needed, additional soil was added to raise soil height within three to four inches of the top of the container. Containers were sorted by soil type and given a rep number (1-3) and a unit number (1-48) as well as color-coded stake (white, blue, green, or red) denoting fertilizer type (Figure 7). Soil and soil amendments were mixed per individual container in large buckets prior to filling. Fertilizer was incorporated into the top half of the container after filling. Containers were then transported to each specific location within the experimental plot (Figure 6). Containers were arranged into three experimental repetitions, spaced two feet between buckets and four feet between rows.

2.8. Planting

Each bucket was seeded with four maize kernels on May 15. After germination, the maize plants were thinned to two plants per container. Per traditional "The Three Sisters" planting method, when maize plants measured 10 - 15 cm, approximately two weeks after planting, six bean seeds and two pumpkin seeds were added per container. Any containers not reaching two maize plants were also reseeded at this time. After germination, beans were thinned to four plants per container, and pumpkins were thinned to one plant per container for a ratio of 2:4:1 maize: bean: pumpkin plants per bucket. If germination rates failed to reach this ratio, containers were reseeded at time of thinning with the number of plants needed to meet the 2:4:1 ratio to ensure each experimental unit was identical for production.

2.9. Irrigation

A spray stake irrigation system was constructed using 7.6 cm diameter piping that was set perpendicular to the experimental rows. Utilizing couplers, the same piping was run between rows of the same experimental rep so that each rep had its own irrigation line. Within each rep, small diameter irrigation tubing was connected to the main irrigation line at the site of each container. The other end of the irrigation tubing was connected to a spray nozzle that was positioned within the bucket with an irrigation stake (Figure 6). Containers were watered one to three times a week depending upon measurement with a moisture reader, receiving 25.4 mm of water at each irrigation cycle.

2.10. Data Collection

Data was collected starting week 4 of the experiment with germination rate for each plant variety and corn height (cm). Data collection occurred every other week through the remainder of the experiment. Sweet corn height (cm), sweet corn tiller number, green bean vine length (cm), green bean vine trifoliate number, pumpkin vine length (cm), and pumpkin vine leaf number were all collected on a biweekly basis.

Sweet corn harvest data was collected on July 23, 2021 and August 4, 2021 in North Dakota and July 28 and August 4 in Minnesota. Harvest timing was determined by husk color that indicated maturity, even if development of the entire cob was incomplete. Weight (g) was determined for each ear of corn including the husk and cob. Even though the Fargo location was within city limits, raccoon damage was recorded before the second harvest. Bean harvest data was collected when bean pods reached 18-to-23-cm in length. The number of individual bean pods and their collective weight (g) were taken per container. Pumpkins harvest data was collected on October 18, 2021 in both North Dakota and Minnesota after the first frost and vines were dead. Total harvest weight (g) was determined for both mature and immature pumpkins collected on that date. Total experimental duration in both locations was 22 weeks and 2 days.

2.11. Experimental Design

The experimental design was a three-factor trial arranged as a completely randomized design with three repetitions. Each replicate consisted of forty-eight containers with each container receiving one of three soil mediums (Minnesota loam, North Dakota clay, and Topsoil), one of four soil amendments (Peat Moss, Straw Topper, Vermiculite, and None), and one of four fertilizer types (Burpee's All Purpose (4-4-4), Bone Meal (6-8-0), Jobe's spikes (10-10-4), and None). Each container represented one experimental unit. All data collected was log transformed due to non-normal distribution and statistically analyzed using an aligned rank transformed ANOVA (R statistical project version 4.2.0, R Foundation, Vienna, Austria). Where appropriate, mean separations were conducted using Tukey's Procedure with P=0.05 and back transformed for presentation ease.

3. RESULTS

The results across the two locations differed in corn ear mass and pumpkin harvest weight due to regional pest and weather conditions. This would indicate that regional recommendations for a horticulture, polyculture containerized production system would need modification according to specific location conditions. Local weather would also determine irrigation needs and schedule. However, since a general recommendation for the MN and ND area was wanted, locations were considered random effects and incorporated into the analysis model so that overall estimations of soil, fertilizer, and mulch effects could be made.

To address nutritional needs for food security, recommended harvest weight standards per crop are 113 grams of corn, 340 grams of beans, 2268 grams of pumpkin, including 590 grams of pumpkin seeds harvested. This would provide a total of 3016 grams, 2485 calories, and 87.9 grams of protein per container. This would more than sufficient nutrition for a single day based upon the Daily Value recommendations. Recommendations for soil, mulch, and fertilizer type will be determined based upon these standards.

Table 7. Total harvest weight recommendations per container with nutritional value per crop

Crop	Weight (g)	Calories	Protein
Corn	113	97	3.7
Bean	340	105	6.2
Pumpkin	2268	590	22.7
Pumpkin Seed	295	1693	87.9
Total	3016	2485	120.5

3.1. Sweet Corn

3.1.1. Stem Height

Final corn height was directly impacted by the interaction between soil and fertilizer types (Table 1). North Dakota clay with Burpee's Bone Meal (6-8-0) had the highest final corn heights, followed by North Dakota clay with Jobe's spikes (10-10-4) (Figure 4). These corn heights were similar to those from containers with Minnesota loam fertilized with Jobe's spikes (10-10-4), Minnesota loam or North Dakota clay unfertilized, North Dakota clay fertilized with Burpee's All Purpose (4-4-4), or Topsoil fertilized with Burpee's Bone Meal (6-8-0) (Table 8). This indicates that many combinations of Soil and Fertilizer types can produce corn stems of sufficient height for corn production in containers. Containers with Topsoil fertilized with Burpee's All Purpose (4-4-4) and no fertilizer had the shortest corn stalks. Shortened corn stalk height directly impacts the plant's ability to produce corn ears.

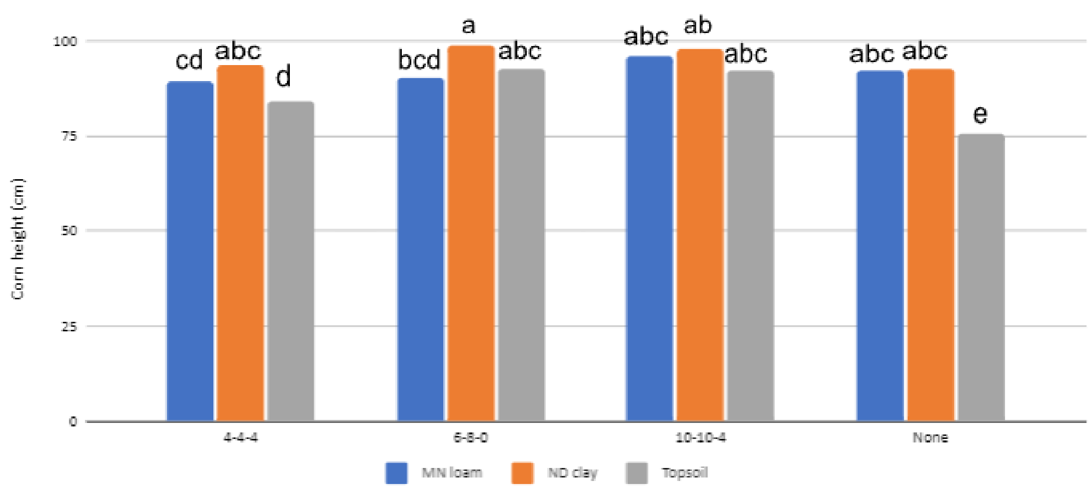

Figure 1. Influence of soil type and fertilizer type on final sweet corn heights when combines over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

3.1.2. Total Ear Weight

Sweet corn yield was significantly impacted by the interaction of fertilizer type and soil type (Figure 2) Sweet corn yield was above the 113 g threshold for food security in all of the containers Topsoil with no fertilizer produced the highest sweet corn ear weight. Minnesota loam combined with either Burpee's All Purpose (4-4-4) and Burpee's Bone Meal (6-8-0) as well as North Dakota clay combined with Burpee's Bone Meal (6-8-0) produced above high total ear weight. The Topsoil combined with Burpee's Bone Meal (6-8-0) fertilizer resulted in the lowest sweet corn ear weight. The variation in the Topsoil results could be due to the formulation of the Topsoil.

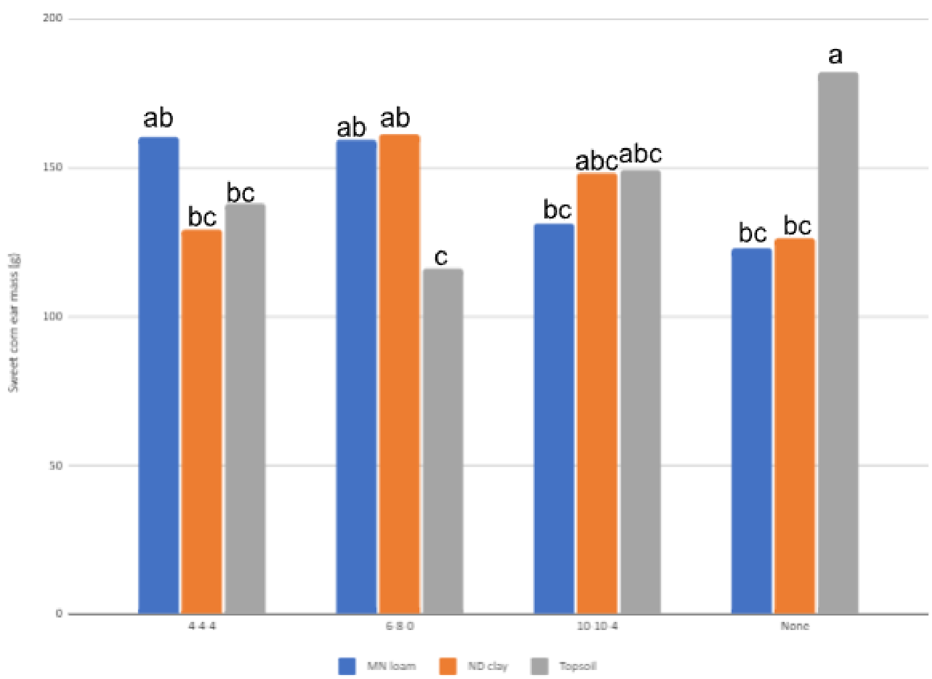

Figure 2. Influence of soil type and fertilizer type on sweet corn total ear weights when combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

3.2. Green Beans

3.2.1. Stem Length

Green bean stem length prior to pod harvest was impacted only by Soil type and Mulch type (Table 7). Containers containing Minnesota loam or North Dakota clay produced stems longer than the containers containing Topsoil. C Containers combining Topsoil where no mulch amendment was added or the containers combining Topsoil with the Straw Topper produced the shortest stem lengths. According to this reach, green bean stems produced well in a variety of Soil types and Mulch types.

Table 8. Influence of container mulches and soil types on green bean stem length with mulch and soil effect separation. Values are estimated marginal means or model predictions on a rank scale

Mulch	Stem Length (cm)
None	148 c
Peat	174 ab
Straw	163 bc
Vermiculite	183 a
Soil Type	
Minnesota Loam	185 a
North Dakota clay	173 a
Topsoil	143 b

3.2.2. Leaf Number

Green bean leaf number was impacted by Soil type, Mulch type, and Fertilizer type. Containers combining Minnesota loam with Vermiculite and the Straw topper as well as the North Dakota clay combined with the Straw topper produced the highest number of leaves per stem (Figure 3). This indicates that the addition of a soil straw topper may help to reduce evaporation in soils with higher water holding capacity keeping available water within the root zone. It also suggests that an amendment that increases water holding capacity, such as vermiculite, to any soil type will have a positive impact on the number of leaves per stem regardless of soil type. Containers combining Topsoil with no mulch amendment or Straw Topper as well as North Dakota clay with no mulch amendment produced the smallest number of leaves per stem. Since the Topsoil already contained a high amount of organic matter, it was negatively impacted by a lack of water holding capacity and the addition of organic matter to the top of the container.

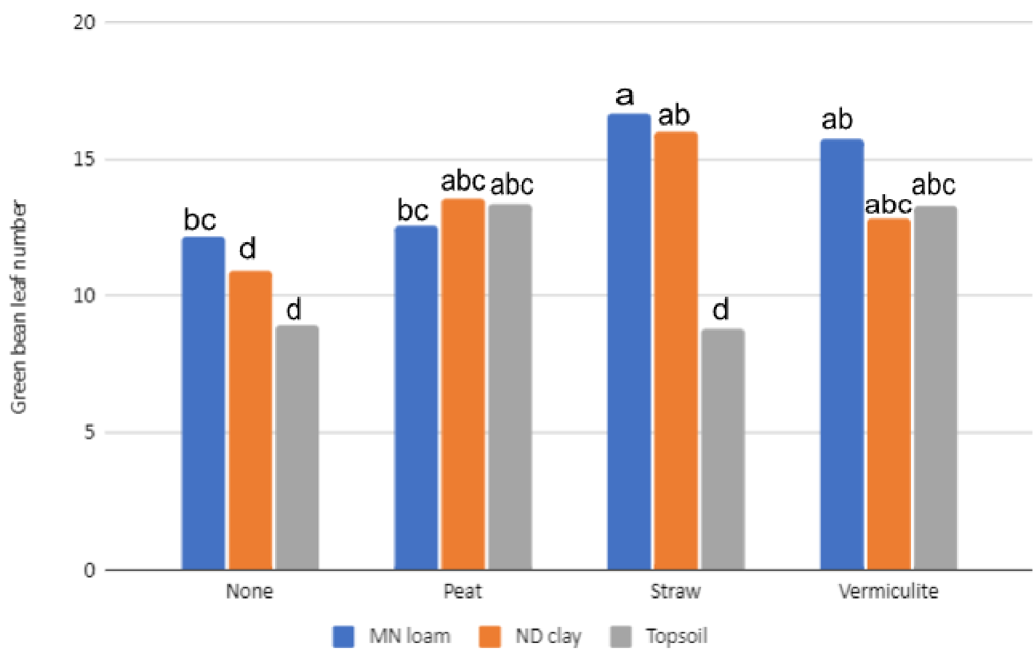

Figure 3. Influence of soil type and mulch on green bean leaf number when combined over both locations over 2021. Values are estimated marginal means or model predictions on a rank scale

Containers combining Minnesota loam with Jobe's spikes (10-10-4) produced the greatest number of leaves per stem, followed by Minnesota loam and North Dakota clay with no additional fertilizer (Figure 4). The high number of leaves per stem in the container receiving no additional fertilizer suggests that this green bean vining variety may not need additional fertilizer to produce a high number of leaves per stem. Containers consisting of Topsoil fertilized with Burpee's All Purpose (4-4-4) and Burpee's Bone Meal (6-8-0) had the lowest number of leaves per stem.

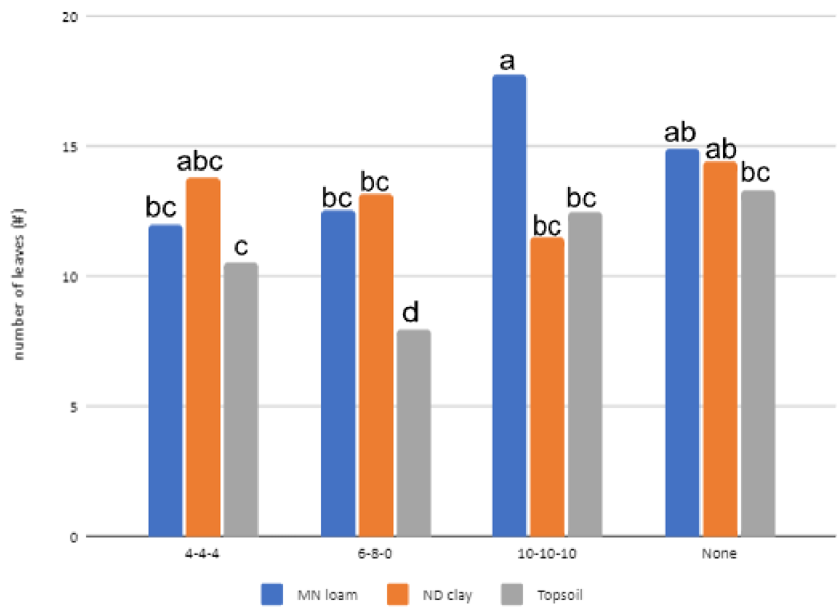

Figure 4. Influence of soil type and fertilizer type on green bean leaf number when combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

3.2.3. Green Bean Pod Weights

None of the containers on average produced high enough harvest weights in grams to reach the suggested 340 g per container needed for food security.

Green bean harvest weight was impacted by Soil type, Mulch type, and Fertilizer type. The containers combining North Dakota clay with the Straw topper produced the highest harvest weight (Figure 5). Containers combining Minnesota loam with the straw topper and Topsoil with vermiculite also produced high total harvest weights. The Minnesota loam combined with Peat Moss, North Dakota clay combined with vermiculite, and Topsoil combined with the Straw topper produced the lowest harvest weights. On average, containers receiving no mulch amendment combined with any Soil type performed well. This confirms the suggestion that this variety of vining green beans is adaptable across soil types without fertilizer to produce long stem lengths and high pod weights.

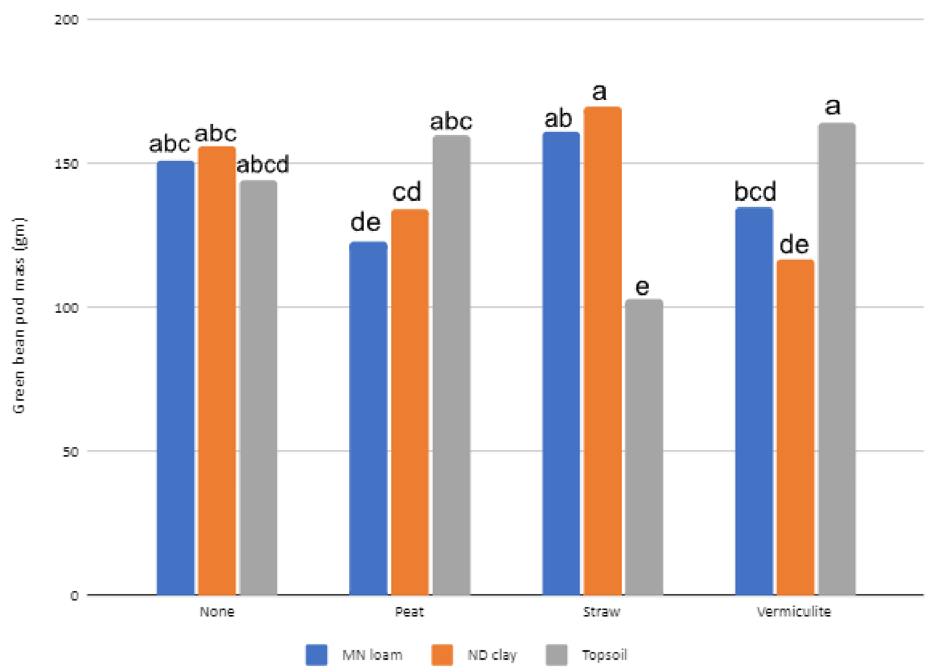

Figure 5. Influence of soil type on mulch on green bean harvest weight when combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

The containers combining with the straw mulch covering fertilized with Jobe's spikes (10-10-4) and Burpee's Bone Meal (6-8-0) produced the highest total green bean pod mass, although there was little significant difference between the top producing Mulch and Fertilizer combinations (Figure 6). The containers combining no fertilizer with the Straw topper, Jobe's spikes (10-10-4) with Peat amendment or no amendment, and Burpee's Bone Meal (6-8-0) produced the lowest green bean pod mass. No additional fertilizer in containers with the Straw topper having in the lowest green bean pod mass may indicate that nitrogen was utilized to break down the Mulch topper instead of being plant available.

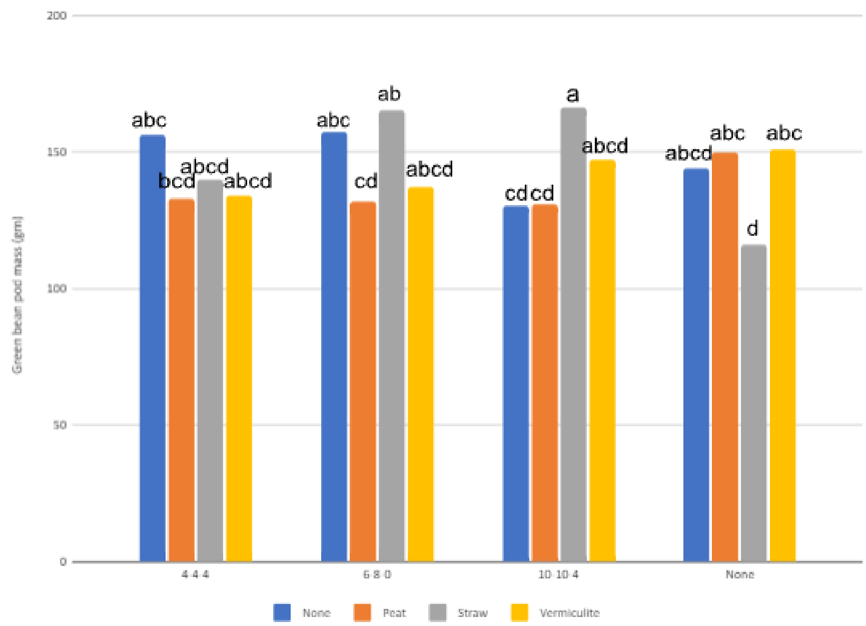

Figure 6. Influence of soil type and fertilizer on green bean harvest weight when combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

3.3. Pumpkin

There was no significant difference in pumpkin vine length or pumpkin leaf number per vine when analyzing Soil type, Mulch type, and Fertilizer type. There was significance in pumpkin harvest weight with Mulch type and Fertilizer type (Figure 7). The containers Combining no fertilizer with no mulch amendment or straw mulch produced the largest pumpkins. The containers combining with no mulch amendment and straw mulch topper also performed well with the Jobe's spikes (10-10-4). Burpee's All Purpose (4-4-4) and Burpee's Bone Meal (6-8-0) performed well when combined with Peat mulch and Vermiculite mulch. No Fertilizer amendment also performed well when combined with Vermiculite. The containers combining vermiculite with Jobe's spikes (10-10-4), Peat amendment with no fertilizer or Jobe's spikes (10-10-4), and no mulch with Burpee's All Purpose (4-4-4) or Burpee's Bone Meal (6-8-0) fertilizers produced the smallest pumpkin harvest weights.

On average, none of the containers in this research reach the standard of 2268g (226.8kg) per container. At the Osakis, MN location, nearly half of all pumpkin vines experienced partial or complete vine death due to squash vine borer. The addition of Safer Diatomaceous Earth (Lancaster, PA) to the base of the pumpkin stems after irrigation did not provide effective control. This loss was factored into the combination of locations and may have influence the stem length, leaves per stem, and total harvest weight of the pumpkins.

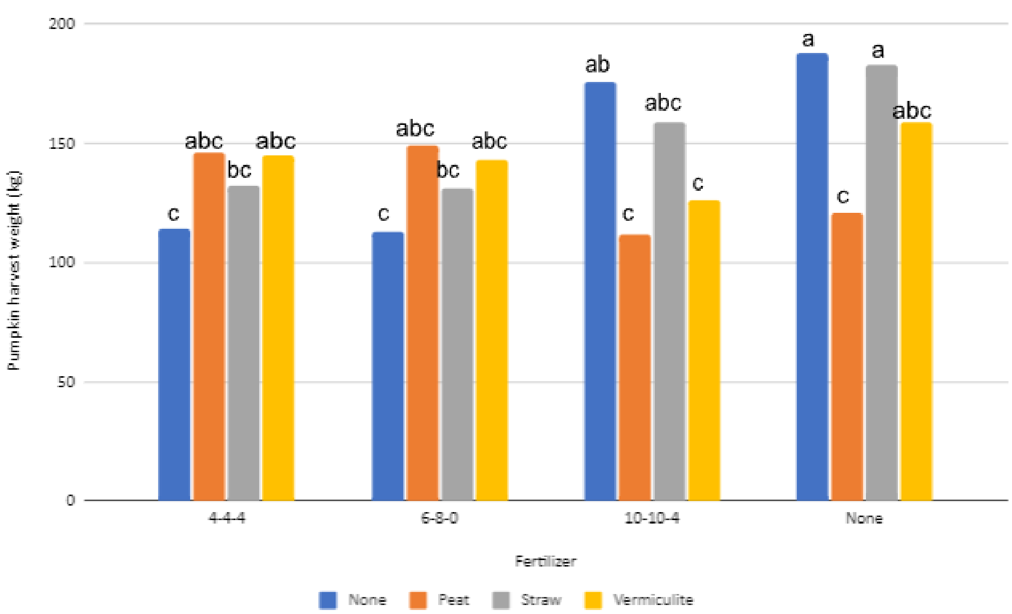

Figure 7. Influence of mulch and fertilizer type on pumpkin harvest weight combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

3.4. Total Harvest Weight

Total harvest weight was impacted by Soil type, Mulch type, and Fertilizer type. Containers Combing Topsoil with vermiculite, Minnesota loam with Straw mulch, and North Dakota clay with Peat mulch had significantly higher total harvest weights per container (Figure 8). This combination could indicate the weakness of each soil type. Topsoil has little water holding capacity which was corrected with the combination of the vermiculite. Minnesota loam has good water holding capacity but is vulnerable to high evaporation rates. The addition of the Straw topper decreased the evaporation rate at the top of the container. North Dakota clay is dense. The addition of the Peat mulch created aeration within the container. The container combining Topsoil and with the Straw mulch produced the lowest total harvest weight. This could indicate both the low water holding capacity of the Topsoil and the additional fertilizer needed to breakdown the additional organic matter of the Straw mulch.

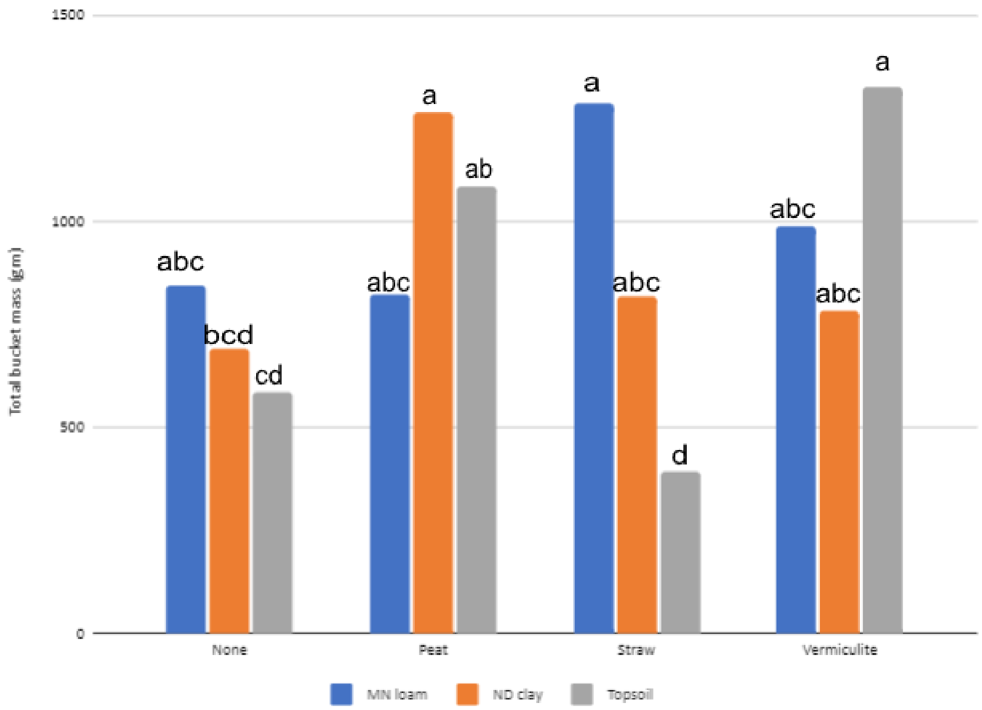

Figure 8. Influence of soil type and mulch on total harvest weight when combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank

Containers combining Minnesota loam with Burpee's All Purpose (4-4-4) and North Dakota clay with Burpee's Bone Meal (6-8-0) produced the largest total harvest weights (Figure 8). The highest individual harvest weights were produced combining all Soil types with Burpee's Bone Meal (6-8-0) (Table 7). Containers combining North Dakota clay with Burpee's All Purpose (4-4-4), Minnesota loam with Burpee's Bone Meal (6-8-0), and Topsoil with no fertilizer also performed above average. Containers combining North Dakota clay with no amendment produced the lowest total harvest weights. This could be due to soil compaction and root restriction with the clay soil.

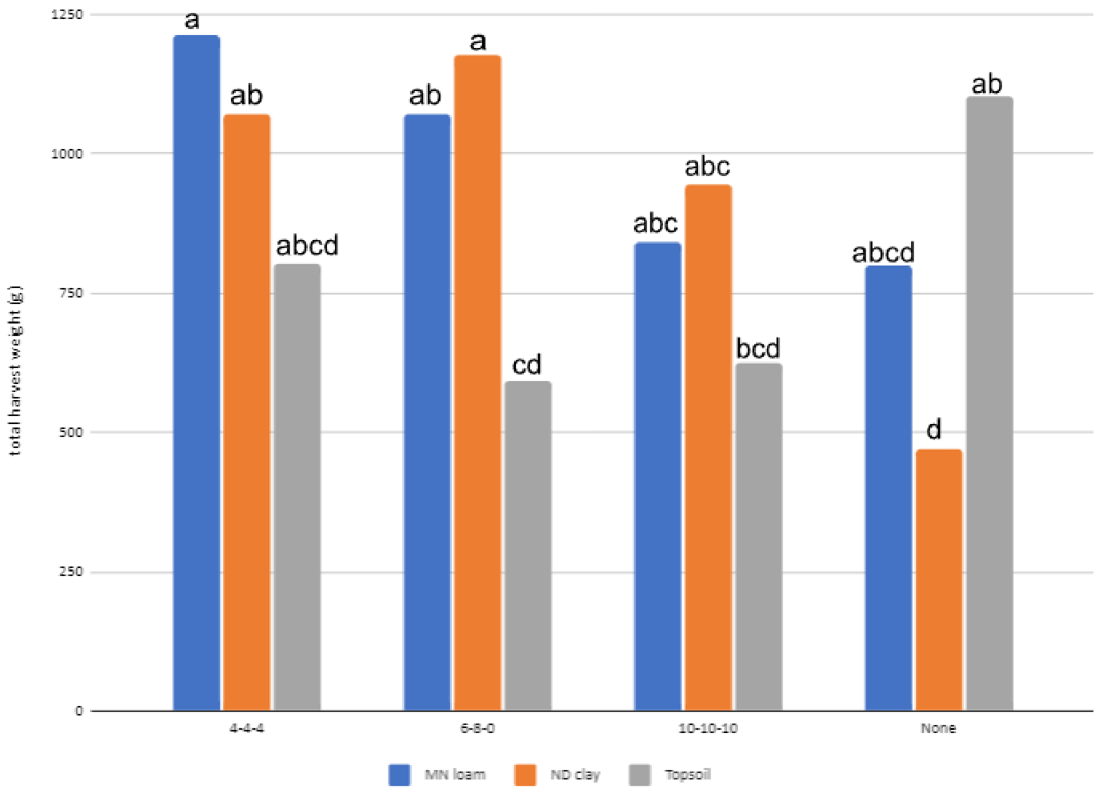

Figure 9. Influence of soil type and fertilizer on total harvest weight when combined over both locations during 2021. Values are estimated marginal means or model predictions on a rank scale.

Minnesota loam, North Dakota clay, and Topsoil all produced the highest harvest weigh per individual container when combined with the Burpee's Bone Meal (6-8-0) (Table 8). The highest harvest weights produced three to four times more per container than the nutritional recommendation (Table 7). This indicates that "The Three Sisters" polyculture can be produced in containers to meet adequate nutritional needs for attaining food security when an optimal combination of Soil type, Mulch type, and Fertilizer type is utilized.

Table 9. Individual container highest recorded harvest weights by soil, mulch, and fertilizer type across locations.

Soil Type	Amendment Type	Fertilizer Type	Harvest Weight (g)
Minnesota	Straw	Burpee's Bone Meal (6-8-0)	11068
North Dakota	Peat	Burpee's Bone Meal (6-8-0)	9381
Topsoil	Peat	Burpee's Bone Meal (6-8-0)	11656

4. DISCUSSION

4.1. Fertilizer

It was assumed that the control-release function of the Jobe's spikes (10-10-4) would provide the best fertilizer option providing consistent fertilizer output throughout the growing season. Though the Jobe's spikes (10-10-4) performed well in analysis of individual containers for green bean leaves per stem and green bean pod mass, the Burpee's All Purpose (4-4-4) produced the highest total harvest weight on average, and the Burpee's Bone Meal (6-8-0) produced the highest corn stalk height and the highest total harvest weight per individual containers across all Soil types. This could be due to both the quality of the slow-release fertilizer and the release rate. Fertilizer spikes were visible within the soil after the harvest of all crops indicating that the release of the fertilizer was not complete. Depending on the length of the production season, incomplete use of slow-release fertilizer hinders the ability of the crops to uptake all fertilizer needs before harvest (Mack 2019). This is consistent with the Jobe's spikes (10-10-4) having smaller total harvest weights than Burpee's Bone Meal (6-8-0) and Burpee's All Purpose (4-4-4), which are quicker to dissolve and becoming plant available, when combined with both the Minnesota loam and the North Dakota clay. This indicates that slow-release fertilizers may not be appropriate for containerized production of polycultures due to lack of sufficient nutrients available weekly for optimal growth.

Even though each container received 400-400-400 NPK throughout the growing season based upon recommendation (Conover, 1996), the choice of retail fertilizers over commercial fertilizer varieties decreased the quality of NPK due to formulation differences. Due to the increase in fertilizer demand when producing a horticulture polyculture, a quick-release, commercial fertilizer would be recommended for future experiments.

Fertilizer options for this experiment were chosen based upon local availability instead of N-P-K percentages. Due to the variation of local supply chains, the fertilizers in this research would be best suited in third world circumstances where large, big-box style stores are likely to carry supplies. To extent this experiment beyond a third world setting and into the global community where food insecurity is highest, fertilizers should be chosen based upon availability. Further research is needed to indicate which fertilizers would be best suited for containerized polyculture production when the local supply chain is small or nonexistent.

4.2. Mulch

Containerized production is above ground allowing for daytime temperature fluctuations both at the top of the container and around the surface area of the container. This increases the likelihood of high evaporation rates. A mulch amendment is needed both to increase the water holding capacity of the soil within the container, such as vermiculite, and on the soil surface, such as the Straw topper, to reduce evaporation rates. Further research might indicate if a combination of the two, a moisture retainer and a top mulch, could further prove beneficial for containerized production.

4.3. Soil Medium

Scott's Premium Topsoil is a peat moss-based mix. This may explain the containers that grew well with corn ear mass, bean pod mass, and pumpkin mass even without the Topsoil being amended. Since the ingredients used to formulate purchased Topsoils differs by manufacturer, production results may differ when utilizing a different Topsoil brand Further research could indicate any significant difference between purchased Topsoil brands. All Soil types in this research performed best when amended to aid each individual soil's weakest qualities. Soil utilized for containerized polyculture production should be examined for soil particle size, organic matter, aeration, compaction, and water retention characteristics to ensure plant roots are not restricted and fertilizer and irrigation is evenly distributed.

4.4. Location

There was variance in the data by location, especially for green bean and pumpkin data. The differences can be explained by differing pest problems in both locations. In North Dakota, green bean and corn ear harvests were decreased due to loss caused by racoon damage. In Minnesota, squash vine borer significantly decreased pumpkin vine length, pumpkin leaf number, and total pumpkin harvest weights. North Dakota and Minnesota also received drier than average weather during the summer of 2021 increasing the rate of irrigation. This would indicate local pests and weather could impact the total harvest weight produced in containerized polyculture production.

4.5. Total Caloric Value

Total caloric and protein values were determined utilizing the nutritional profile for "The Three Sisters" (Table 1). These calculations were determined with equal parts corn, bean, and pumpkin. As the containers in this research do not have equal parts of each crop, the final caloric and protein value of the containers was determined per 100 g of each crop (Table 9). Total harvest weights across locations, soil type, fertilizer type, and mulch type averaged 1600 g, with the highest harvest weights above 11,000 g (Table 8). The total caloric value and total protein were calculated on the highest total harvested weight per soil type (Table 9). With these calculations, one container provides approximately three to four days' worth of calories and seven to ten days' worth of protein. This would provide a potential supplemental nutrition source based upon the number of containers in the production model. Containerized polyculture production is economically, logistically, and nutritionally feasible means to provide an individual or family.

4.6. Need for Future Research

Due to the small-scale and small economic impact, research on containerized production has been limited largely to the nursery and greenhouse industry which does not expect plants to reach maturity within the growing container. Further research on containerized production is needed to determine the optimal container size, crop root dynamics, the irrigation method and schedule, the fertilization method and schedule, and the polyculture combination that would produce the highest harvest weights and the highest nutritional density.

Even when considering the production of "The Three Sisters" for fresh crop production, different varieties than those utilized in this research could be considered. Corn varieties breed for containers that produce average corn ear masses on small stalks. When combined with a green bean variety with a vining habit green bean, as chosen for this research, the green bean vine outgrew the corn stem height, requiring stakes to prevent the green bean stems and corn stems from falling sideways.

A pie pumpkin variety was chosen as the winter squash in this research due to its ability to be produced in containers and the edible quality of the squash flesh. Further research would indicate if another variety of winter squash would produce a higher harvest weight per container. The quantity of seeds per winter squash should also be considered as the nutritional value of the winter squash seeds would vary based upon the quality and quantity of the seed harvest. A winter squash variety with moderate squash harvest weight and high volume of seeds would optimize the nutritional value.

This research focused on fresh-pick corn, green bean, and winter squash varieties. Further research could indicate if mature, dry harvest varieties of corn and bean or a combination of mature and fresh harvested varieties would increase the overall harvest weight and nutritional value of “The Three Sisters” when used in containerized production.

With further research, “The Three Sisters” containerized production could increase total harvest weights increasing the number calories and the amount of protein produced per container. This research indicates that optimal production could produce one to four days of nutritional value per container. The greater the harvested weight and the nutritional value per container the less containers are needed to increase food security. Containerized polyculture production could allow producers to supplement their dietary needs with cost productive, spatially efficient, and formulaic production system. This type of production system will not feed the masses but has the potential to effectively increase food security for individuals, families, and small producers.

REFERENCES

Adair, M. J. 2003. People and plants in ancient eastern north america. Great Plains Paleoethnobotany, 258-346. Smithsonian Books, Washington, D.C.

Bernai, G. R., B. Tlusty, C. Estevez de Jensen, P. van Berkum, and P. H. Graham. 2004. Characteristics of rhizobia nodulating beans in the central region of minnesota. Canadian J. of Microbiology. 50:1023–1031.

Bilderback, T. E. and W. C. Fonteno. 1987. Effects of container geometry and media physical properties on air and water volumes in containers. J. of Env. Hort. 5(4):180-182.

Bilderback, T. E., S. S. L. Warren, J. S. Owen, & J. P. Albano. 2005. Healthy substrates need physicals too! Hort Tech. 15(4): 747-751.

Bilderback, T. E., J. S. Owen, J. Atland, & G. Fain. 2013. Strategies for developing sustainable substrates in nursery crop production. Acta Horticulturae 1013:43-56. DOI:10.17660/ActaHortic.2013.1013.2

Blaise, D., A. Manikandan, N. D. Desouza, B. Bhargavia, & J. Somasundaram. 2021. Intercropping and mulching in rain-dependent cotton can improve soil structure and reduce erosion. Env. Advances. 4. https://doi.org/10.1016/j.envadv.2021.100068.

Burnett, S. E., N. S. Mattson, & K. A. Williams. 2016. Substrates and fertilizers for organic container production of herbs, vegetables, and herbaceous ornamental plants grown in greenhouses in the United States. Scientia Horticulturae. 208: 111-119.

Cantliffe, D.J. 1993. Pre- and postharvest practices for improved vegetable transplant quality. HortTech. 3:415-417.

Carlile, W. R. & I. Beford. 1988. Plant growth in container medium amended with calcined clay. Acta Hort, 221:117-132.

Cox, D. A. 1993. Reducing nitrogen leaching-losses from containerized plants: The effectiveness of controlled-release fertilizers. J. Plant Nutr. 16:533-545.

Davidovits, J. 1988. The famine stele provides the hieroglyphic names of chemicals and minerals involved in the construction of pyramids. Geopolymer Institute. Cairo, Egypt.

Dillehay, T. D., J. Rossen, T. C. Andres, & D. E. Williams. 2007. Preceramic adoption of peanut, squash, and cotton in northern peru. Science. 316:1890-1893.

Food and Agriculture Organization of the United Nations. 1992. Maize in human nutrition. Food and Nutrition Series No. 25. Available at: http://www.fao.org/docrep/T0395E/T0395E00.htm.

Food and Agriculture Organization of the United Nations. 2015. The economic lives of smallholder farmers. Food and Agriculture Organization for the United Nations. Rome.

Food and Agriculture Organization of the United Nations. 2021. The state of food security and nutrition in the world for 2021. Food and Agriculture Organization for the United Nations. Rome.

Food and Agriculture Organization of the United Nations. 2022. Impact of the Ukraine-Russia conflict on global food security and related matters under the mandates of the Food and Agriculture Orgaization of the United Natinos (FAO). Available at: https://www.fao.org/3/ni734en/ni734en.pdf.

Food and Drug Administration. 2020. Daily Value and Percent Daily Value: CHanges on the New Nutrition and Supplement Facts Labels. FDA. Available at: https://www.fda.gov/food/new-nutrition-facts-label/daily-value-new-nutrition- and-supplement-facts-lab els

FoodData Central. 2019. SR legacy. USDA. Available at: https://fdc.nal.usda.gov/fdc-app.html#/food-search

Fung, K. M., A. Tai, T. Yong, X Liu, & H Lam. 2019. Co-benefits of intercropping as a sustainable farming method for safeguarding both food security and air quality. Environ. Res. Lett. 14:044011.

Hart, J. P. 2008. Evolving "The Three Sisters": the changing histories of maize, bean, and squash in new york and the greater northeast. Current Northeast Paleobotany II, New York State Museum Bul. 512:87-99.

Hanming, H. et. al. 2011. The effect of intercropping of maize and soybean on microclimate. IFIP Advances in Information and Communication Technology. DOI: 10.1007/978-3-642-27278-3_27.

Hesser, L. 2006. The man who fed the world: nobel peace prize laureate norman borlaug and his battle to end world hunger. Fireside Press, Incorporated

Hill, C. 2020. Returning the 'three sisters' – maize, beans and squash – to native american farms nourishes people, land and cultures. The Conversation. Available at: https://theconversation.com/returning-the-three-sisters-maize-beans-and-squash-to-native-american-far ms-nourishes-people-land-and-cultures-149230.

Holmer, R. 2002. Container gardening: a way of growing vegetables in the city. Urban Food International. DOI: 10.13140/2.1.4083.5368

Kim, H.S. & K. H. Kim. 2011. Physical properties of the horticultural substrate according to mixing ratio of peatmoss, perlite and vermiculite. Korean Journal of Soil Science and Fertilizer. 44(3):321-330.

Kim J. K., R. A .Shawon, J. H. An, Y. J. Yun, S. J. Park, J. K. Na, & K. Y. CHoi. 2021. Influence of substrate composition and container size on the growth of tissue culture propagated apple rootstock plants. Agronomy. 1(12):2450. DOI:10.3390/agronomy11122450.

Krizek, D.T., A. Carmi, R.M. Mirecki, F.W. Snyder, & J.A. Bruce. 1985. Comparative effects of soil moisture stress and restricted root zone volume on morphogenetic and physiological responses of soybean (Glycine max (L.) Merr.). J. Expt. Bot. 36:25-38.

Lamack, W. F. & A. X. Niemiera. 1993. Application method affects water application efficiency of spray stake-irrigated containers. HortScience. 26: 625-627. DOI: 10.21273/HORTSCI.28.6.625.

Landon, A. J. 2008. The how of "The Three Sisters": the origins of agriculture in mesoamerica and the human niche. Nebraska Anthropologist 23:110–124.

Lewandowski, S. 1987. Diohe'ko, "The Three Sisters" in seneca life: implications for a native agriculture in the finger lakes region of new york state. Agriculture and Human Values. 4:76-93. DOI:10.1007/BF01530644.

Liebman, M. & E. Dyck. 1993. Crop rotation and intercropping strategies for weed management. Ecol Appl. 3(1):92-122. DOI: 10.2307/1941795

Mack R., J. S. Owen Jr, A. X. Niemiera, & D. J. Sample. 2019. Validation of nursery and greenhouse best management practices through scientific evidence. HortTech. 29(6): 700-715.

Martinez, R. T. 2007. An evaluation of the productivity of the native american 'three sisters' agriculture systems in northern wisconsin. Univ. of WI., Stevens Point. Available at: https://minds.wisconsin.edu/handle/1793/81177.

Mason et. al. 2008. Consumer preference for price, color harmony and care information of container gardens. HortScience. 43:380-384.

Midega, C. A. O., D. Salifua, T. J. Bruceb, J. Pittchara, J. A. Pcikett, & Z. R. Khana. 2014. Cumulative effects and economic benefits of intercropping maize with food beans on Striga hermonthica infestation. Field Crops Research. 155:144-152. DOI: 10.1016/j.fcr.2013.09.012.

Mt. Pleasant, J. 2006. The science behind "The Three Sisters" mound system: an agronomic assessment of an indigenous agricultural system in the northeast. In Histories of Maize: MultidisciplinaryApproaches to the Prehistory, Biogeography, Domestication, and Evolution of Maize, edited by J. Staller, R. Tykot, and B. Benz, pp. 529–538. Academic Press, Burlington, Massachusetts.

Mt. Pleasant, J. 2016. Food yields and nutrient analyses of "The Three Sisters": a Haudenosaunee cropping system. Ethnobiology Letters. 7(1): 87-98.

Mt.Pleasant, J. & R. F. Burt. 2010. Estimating productivity of traditional iroquoian cropping systems from field experiments and historical literature. Journal of Ethnobiology 30:52–79. DOI:10.2993/0278-0771-30.1.52

NeSMith, D. S. 1993, Influence of root restriction on two cultivars of summer squash (Cucurbita pepo L.). J. Plant Nutr. 16:421-431.

NeSmith, D. S., D. C. Bridges, & J. C. Barbour. 1992. Bell pepper responses to root restriction. J. Plant Nutr. 15:2763-2776.

NeSmith, D. S. & J. R. Duval. 1998. The effect of container size. HortTech. 8(4): 495-498.

Nikolaou, G., D. Neocleous, N. Katsoulas, & C. Kittas. Irrigation of greenhouse crops. Hort. *5*(1), 7. https://doi.org/10.3390/horticulturae5010007.

Nyawade, S. O., N. N. Karanja, C. K. K. Gachene, H. I. Gitari, E. Schulte-Geldrmann, & M. L. Parker. 2019. Short-term dynamics of soil organic matter fractions and microbial activity in smallholder potato-legume intercropping systems. Applied Soil Ecology. 142: 123-135. DOI: 10.1016/j.apsoil.2019.04.015.

Owen, Jr. J. 2006. Clay amended soilless substrates: increasing water and nutrient efficiency in containerized crop production. N.C. State Univ., Raleigh. Available at: https://repository.lib.ncsu.edu/handle/1840.16/4765.

Parker A. 1910. Iroquois uses of maize and other food plants. *New York State Museum Bulletin* 144:5–113. Available at: http://www.nysm.nysed.gov/publications/bulletins.

Peterson, T.A., M.D. Reinsel, & D.T. Krizek. 1991a. Tomato (*Lycopersicon esculentum* Mill. cv 'Better Bush') plant response to root restriction. Alteration of plant morphology. J. Expt. Bot. 42:1233-1240.

Peterson, T. A., M.D. Reinsel, & D.T. Krizek. 1991b. Tomato (*Lycopersicon esculentum* Mill. cv 'Better Bush') plant response to root restriction. Root Respiration and ethylene generation. J. Expt. Bot. 42:1241-1249.

Reyes-Garcia, V. & P Benuei. 2019. Exploring pathways to link agrobiodiversity and human health. Agrobiodiversity Integrating Knowledge for a Sustainable Future. MIT Press. 225-237.

Santalla, M., A. P. Rodina, P.A. Casquero, & A. M de Ron. 2001. Interactions of bush bean intercropped with field and sweet maize. Euro Journal of Ag. 15 (3): 185-196.

Sibhatu, K. T. & M. Qaim. 2017. Rural food security, subsistence agriculture, and seasonality. PLoS ONE 12(10): e0186406.

UNICEF. 2020. Levels and trends in child malnutrition. UNICEF, WHO, World Bank Group. Available at: https://www.who.int/publications/i/item/9789240025257.

Van Cotthem, W. 2016. Container gardening for the poor the hungry and the malnourished. Ghent Univ., Ghent. Available at: https://www.researchgate.net/publication/321484019_Container_gardening_for_the_poor_the_hungry _and_the_malnourished.

Walters, S. A. & B. H. Taylor. 2006. Effects of honeybee pollinations on pumpkin fruit and seed yield. HortScience. 41:370-373.

Wehner, T. C. & R. Naegele. 2018. Cucumber cultivars for container gardening and the value of field trials for predicting cucumber performance in containers. HortScience.DOI:10.21273/HORTSCI11955-17.

APPENDIX

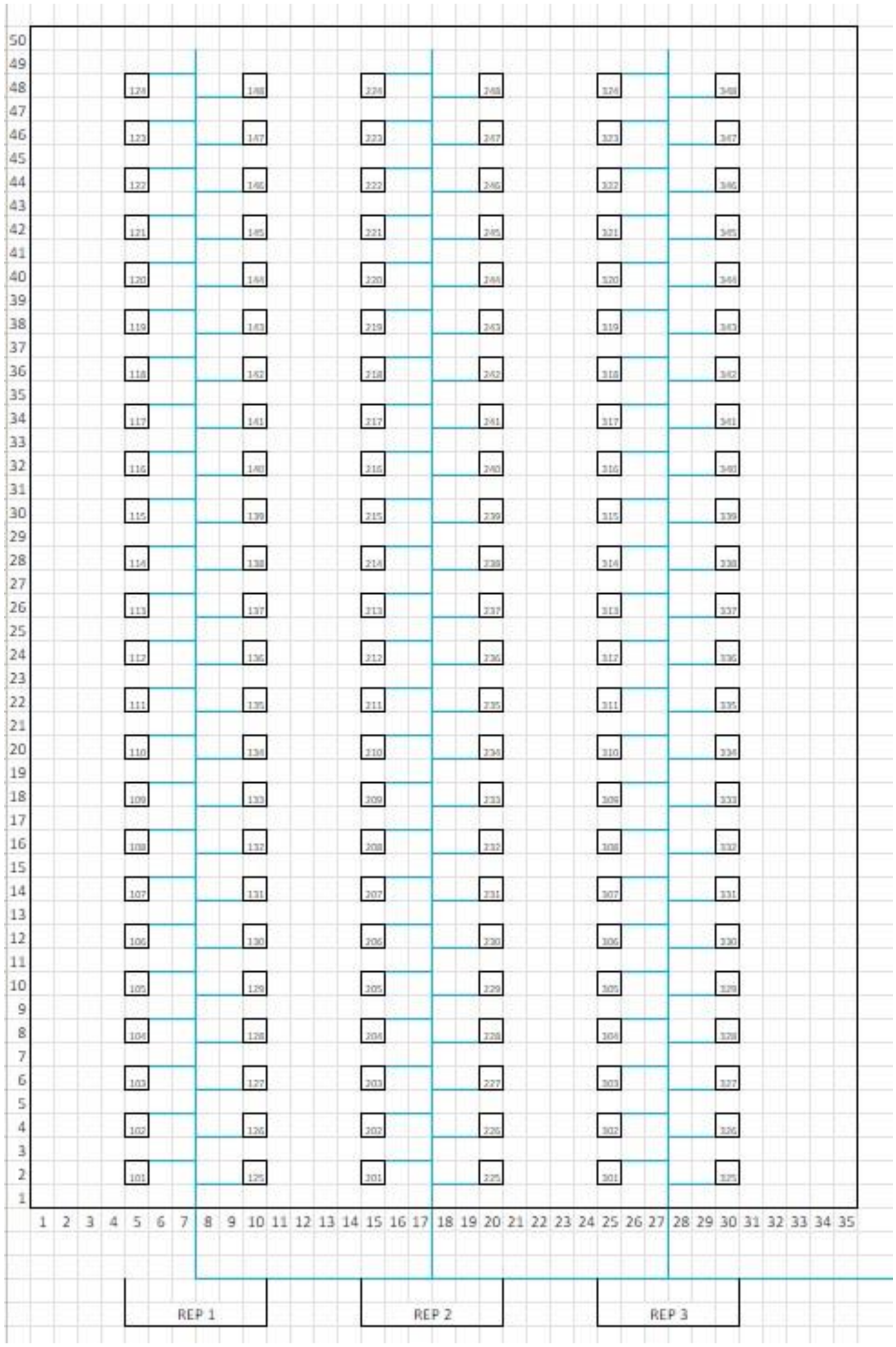

Figure A.1. Experimental plot and irrigation construction.

.	SOIL	MULCH	FERT	REP 1	REP 2	REP 3	Marker Color
1	Top	None	None	101	215	326	white
2	Top	None	10-10-4	102	205	348	blue
3	Top	None	6-8-0	103	227	308	green
4	Top	None	4-4-4	104	233	325	red
5	Top	Verm	None	105	212	320	white
6	Top	Verm	10-10-4	106	225	337	blue
7	Top	Verm	6-8-0	107	240	314	green
8	Top	Verm	4-4-4	108	224	343	red
9	Top	Peat	None	109	203	332	white
10	Top	Peat	10-10-4	110	219	309	blue
11	Top	Peat	6-8-0	111	244	301	green
12	Top	Peat	4-4-4	112	232	336	red
13	Top	Straw	None	113	211	303	white
14	Top	Straw	10-10-4	114	242	319	blue
15	Top	Straw	6-8-0	115	239	346	green
16	Top	Straw	4-4-4	116	248	318	red
17	MN	None	None	117	209	327	white
18	MN	None	10-10-4	118	223	331	blue
19	MN	None	6-8-0	119	241	307	green
20	MN	None	4-4-4	120	213	342	red
21	MN	Verm	None	121	246	335	white
22	MN	Verm	10-10-4	122	201	306	blue
23	MN	Verm	6-8-0	123	237	345	green
24	MN	Verm	4-4-4	124	230	334	red
25	MN	Peat	None	125	220	313	white
26	MN	Peat	10-10-4	126	234	340	blue
27	MN	Peat	6-8-0	127	208	305	green
28	MN	Peat	4-4-4	128	245	347	red
29	MN	Straw	None	129	218	317	white
30	MN	Straw	10-10-4	130	222	344	blue
31	MN	Straw	6-8-0	131	204	310	green
32	MN	Straw	4-4-4	132	238	323	red
33	ND	None	None	133	229	330	white
34	ND	None	10-10-4	134	235	312	blue
35	ND	None	6-8-0	135	226	339	green
36	ND	None	4-4-4	136	221	302	red
37	ND	Verm	None	137	216	341	white
38	ND	Verm	10-10-4	138	243	315	blue
39	ND	Verm	6-8-0	139	214	328	green
40	ND	Verm	4-4-4	140	247	304	red
41	ND	Peat	None	141	202	333	white
42	ND	Peat	10-10-4	142	228	321	blue
43	ND	Peat	6-8-0	143	231	338	green
44	ND	Peat	4-4-4	144	207	322	red
45	ND	Straw	None	145	236	311	white
46	ND	Straw	10-10-4	146	210	329	blue
47	ND	Straw	6-8-0	147	217	324	green
48	ND	Straw	4-4-4	148	206	316	red

Figure A.2. Treatment List

Table A.1. Total caloric and protein value per harvested crop and total harvest weight per container.

	Corn (g)	Corn Cal	Corn Prot	Green Bean (g)	Green Bean Cal	Green Bean Prot	Pump (g)	Pump Cal	Pump Prot	Pump Seed (g)	Pump Seed Cal	Pump Seed Prot	Total (g)	Total Cal	Total Prot	Daily Value % Cal	Daily Value % Prot
MN	308	258	9.81	358	108.5	6.41	10380	260	10	1349	7746	387	12395	8372.5	413.22	419	826
ND	414	344	13.08	338	93	5.49	8629	223.6	8.6	1222	7013	358	9381	7673.6	385.17	384	770
Top	276	232.2	83.7	240	83.7	4.941	11140	286	11	1448	8312	432	11656	8913.9	531.641	446	1063