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TWO INTER-ROW SPACING AND STAGGERED PLANTING ON COLLARD (*Brassica oleracea* L. var. *acephala* DC.) YIELD IN A WIREGRASS TUNNEL HOUSE

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Abstract

There is interest among small vegetable producers to grow collards in Tunnel Houses during the winter months. Consequently, the purpose of this study was to determine if collard yields could be increased by reducing row spacing and increasing plant density. This study had four treatments replicated three times, and "Georgia" and "Hi-Crop Hybrid" collards were transplanted on single, and staggered rows spaced 18" and 24" apart in a split-split-plot design. At 45 days after transplanting 50% of the leaves from all plants in each treatment were harvested, counted, and weighed. The results showed staggered 18 and 24" rows increased yields by 43 and 51%, respectively, over single planted rows for both varieties. Staggered rows incurred higher planting costs, but increased net returns to management. The increase in yield was variety-dependent, thus suggesting that the genetic potential of the varieties needs to be considered when using plant density to increase yields.

Keywords: Inter-Row spacing, Staggered Planting, Collard Varieties, Wiregrass Tunnel House

Introduction

Tunnel Houses (THs) are protected structures designed to provide vegetable producers an early start in spring or to extend the growing season in the fall/winter months in the Southeastern part of the U.S. (Blomgren and Frisch, 2007; Ghent, 1990; Khan et al., 1994; Wells, 1993). The Wiregrass model TH was designed and built through a grant from the United States Department of Agriculture Natural Resource Conservation Service [USDA NRCS], and it is offering financial assistance to historically underserved producers, and beginning farmers, to implement various conservation practices, including the use of THs (USDA NRCS, 2014).

The two factors which have stimulated the interest of small farmers in adopting THs in their farming operations are (1) the growing interest of the public in knowing where and how their produce is grown, and (2) the USDA NRCS offering financial assistance to construct THs. However, the acceptance rate of small farmer growers is conditioned by the lack of sufficient information on what and how to grow crops in THs, and the expectations of profitability for various crop combinations (Galinato and Miles, 2013; USDA NRCS, 2004). Regarding profitability, enterprise budgets have been developed for TH tomatoes and leafy vegetables (Galinato, 2012; Kaiser and Ernst, 2017). Yet, there is a lack of information on the production costs and net returns for other vegetables grown in THs, for example, collards.

Previous TH studies (Sparks et al., 2018; Walton et al., 2018) investigated the partial harvest and regrowth of collard leaves under tunnel house conditions. These studies were conducted using the standard 2 ft. inter- and 1 ft. intra-row spacing. Since the ground space within a TH is limited, the measures available for increasing yield are condensed inter-row spacing, and/or increased plant density by planting staggered rows (these are rows where the plants are planted in a zig-zag pattern and this allows the grower to have about twice the number of plants in a given area). Therefore, the main objectives of this study were to (1) compare yields when rows are inter-spaced at 18 and 24 inches and planted as single vs. staggered; (2) determine if there are varietal differences in yield when collards are planted at an inter-row spacing of 18 and 24 inches, and also evaluate the effects of single vs. staggered plant rows, and (3) develop a summarized projected enterprise budget using the data from this study to compare costs and net returns from single vs. staggered planted rows spaced 18 and 24" apart in a 20'x 48' Wiregrass Tunnel House.

Literature Review

Previous Row Spacing Studies

Plant spacing is one of the methods used to increase the yield on a given piece of land by farmers in many parts of the world, but it can affect fruit quality, plant growth, and overall crop productivity (Abrha et al., 2015). Adigun et al. (2017) reported that increasing the plant density of certain crops resulted in less weed competition and improved the light interception of the crop leaves which resulted in higher yields. Plant spacing also affects the number of plants that makes up the total population of a given crop and depending on the population size the final yield can be affected (Amjad et al., 2002). Wide row spacing affects plant density by having fewer plants per/acre while narrower row spacings can result in a higher number of plants that compete for light, nutrients, and water, thus reducing crop yields (Idoko et al., 2018).

Adigun et al. (2017) investigated the effects of three different inter-row spacings (60, 75, and 90 cm), two rates of pre-emergence herbicides (metolachlor plus prometryn (codal)), and hoe weeding on yield and weed control for groundnuts. They concluded that an inter-row spacing of 60 cm and an application of codal at 1.0 kg a.i/ha followed by supplementary hoe weeding at 6 wks after planting, increased groundnut pod yield, and controlled weeds comparable to the hoe weeded control in both years of the study. Idoko et al. (2018) assessed the effect of three inter-row spacing (50, 75, and 100cm) and three intra-row spacing (20, 30, and 40cm) on yield, plant height, number of branches, leaf area, number of capsules per plant, capsule length, number of seeds per capsule, and 100-seed weight of sesame. They concluded that an inter-row spacing of 50 cm along with an intra-row spacing of 20 cm produced the highest seed yield. However, the widest inter-row spacing of 100 cm and 40 cm intra-row spacing had the highest plant height, number of branches, leaf area, number of capsules per plant, capsule length, number of seeds per capsule, and 100-seed weight.

Dawuda et al. (2011) investigated the response of carrots to three rates of chicken manure (10, 15, 20 t/ha) one application of 300 kg/ha of granular NPK (15-15-15), and two inter-row spacing of 30 and 20 cm. They reported that the yield, vegetative growth, and root length of carrots improved when the inter-row spacing was 20 cm and treated with either 15 or 20 t/ha of chicken manure. However, wider row spacing and a lower rate of chicken manure had lower yields. They also noted that the incidence of southern blight (*Sclerotium rolfsii*) increased when chicken manure was applied at 20 t/ha. The application of 300 kg/ha of granular NPK (15-15-15) did not make a significant difference in the yield of carrots. In a further study, mung beans were assessed, in an experiment using four inter and intra-row spacing (25, 30, 35, and 40 cm, 5, 10, 15, and 20 cm). The results showed that maximum mung bean yield was obtained at an inter- and intra-row spacing of 30 and 5 cm, respectively. However, maximum plant height, the highest number of branches, and seeds per plant were obtained at an inter-row spacing of 40 cm, and intra-row spacing of 5 cm (Gebremariam and Baraki, 2018).

Madisa et al. (2015) evaluated how five intra-row spacings of 30, 45, 60, 75, and 90 cm, would affect okra yield. They reported that the 30 cm row spacing significantly increased plant height, but the plants were weak. The plant spacing of 90 cm significantly increased plant weight, the number of branches, and leaves. The maximum fruit weight was obtained in the widest spacing (90 cm) because the plants were stronger compared to those with closer spacing. Amjad et al. (2002), in another study, using "Clemson Spineless" okra was evaluated at three Intra-row spacing (15, 30, or 45 cm), and four rates of NPK (Nitrogen, Phosphorus, and Potassium) fertilizer. All of the P and K with half rate of N were applied at the time of planting, while the remaining half of N was applied at flower initiation. The widest intra-row spacing distance significantly increased pod length, number of pods per plant, the average weight of pod, and yield per plant. However, the highest green pod, and seed yield per hectare, were obtained at the higher fertilizer doses with the closest plant spacing.

Abrha et al. (2015) also evaluated the yield of "Roma-VF" tomato spaced on rows at 50 and 100 cm and intra-spaced at 20, 30, and 40 cm on these rows. The highest total and marketable fruit yield were obtained from the closest intra-row spacing of 20 cm and inter-row spacing of 50 cm. However, the 40 cm intra-row and the 100 cm inter-row spacing had the lowest total and marketable fruit yield. These results showed that high yields of tomatoes can be obtained at closer intra and inter-row spacing (i.e., at higher plant densities). Masa et al. (2017) in a corresponding study, examined the yield of two varieties of common beans that were evaluated at 30, 40, and 50 cm inter and at 7, 10, and 13 cm intra-row spacings. The results showed that an increase in the inter-row spacing from 30-50 cm, resulted in reduced plant height, days to physiological maturity, and grain yield, while pods per plant and hundred seed weight increased. As plant spacing within rows increased leaf area index, plant height, dry biomass, and grain yield decreased, while leaf area, pods per plant, seeds per pod, and hundred seed weight increased.

Cultivation of Collards and Related Studies

Collards can be grown in a variety of soils, however, lighter well-drained soils with a pH ranging from 5.5-6.5 are best for growing collards (Sanders, 2001). Currently, collards are produced commercially in four ways, namely, (1) plants are grown in early spring, and leaves are harvested approximately 60 days later, (2) plants are grown in early spring, and leaves are harvested in late spring, plants are carried over to the fall season when whole plants are harvested, (3) seedlings are transplanted during August-September and leaves are harvested from October to December, and (4) seeds are directly sown in the soil during early spring, thinned after emergence, and carried over into the fall season (Sanders, 2001). Collards are harvested and sold in bunches of two or three plants and then packed in 12 to 24 bunches per box topped with ice, before the sale (Coolong, 2017). However, for some markets, only the leaves are harvested, washed, and petioles removed, after which the leaves are chopped and bagged for the market (Olson and Freeman, 2008).

Botanically, collards are classified as biennials, but under selected conditions, they are considered perennials. The brassica family of plants originated in the Mediterranean region of the world and are best grown in cool climates with relatively high humidity. The optimum temperature for growth is between 50 and 77ºF (10 and 25ºC). Temperatures above 80ºF (27ºC) slow or arrest growth. Ideal growing regions are coastal areas where the climate is cool with moderate to heavy rainfall during the vegetative stage of growth. Prolonged periods of low temperatures during the growing period can cause collards to bolt (grow flowers than more leaves). Bolting is initiated by an interaction of plant size (age) and cold temperatures. Usually, when plants are exposed to temperatures of 39ºF-50ºF for 4-6 weeks, bolting will occur. Large plants are more susceptible to bolting than young plants. There are also varietal differences in susceptibility to bolting (Olson and Freeman, 2008; McCormack, 2005).

Sparks et al. (2018) and Walton et al. (2018) conducted studies where they compared harvesting 50% of collard leaves and 100% of the leaves from two varieties under TH conditions. They stated that plants in the treatment where 50% of the leaves were harvested had increased leaf weight and numbers in successive harvests, compared to reduced leaf weights and numbers from plants where 100% of the leaves were harvested. In addition, leaf recovery rates were higher for plants with 50% of their total leaves harvested, which ranged from 114 – 224% compared to 42- 101% for those plants which had 100% of their leaves harvested. In a related study, Jackson et al. (2021) investigated the effect of harvesting collard leaves from three varieties of collards every 18, 21, and 25 days, after the crop matured. They reported that the highest leaf weights were obtained when 50% of the leaves were harvested every 18 days for two of the varieties used in the study. However, yields declined after two harvests, and this was attributed to the prevailing weather conditions.

Enterprise Budgets

An enterprise budget is an itemized record of all projected revenue and expenses associated with a specific farm enterprise, which functions to determine its profitability and for comparisons with alternative enterprises on the farm. Enterprise budgets are developed on the basis of a common unit such as an acre of sweetpotatoes, peas, okra, or one "head" of livestock, for example, cattle. There are different ways in which an enterprise budget can be presented but generally, they include the following sections: revenue/receipts/returns, variable costs, and fixed costs, gross revenue/receipts/returns, and net revenue/receipts/returns. When estimating revenue and yield, it is best to use yields and prices which are obtained under normal growing conditions. Hired labor, fuel for farm equipment, seed and fertilizer costs, and veterinary services, are examples of variable costs which fluctuate based on the acreage of the crop, or the number of livestock produced. Fixed costs are costs that remain the same regardless of the acreage of the crop, or the number of livestock produced (Sharp, 2008). In general, enterprise budgets are used to determine which management practice to implement from a number of competing systems to achieve the highest returns.

Khan et al. (1989) developed a number of enterprise budgets for the early production of watermelons, tomatoes, and okra, using clear and black mulches with or without row covers, and bare soil. They reported that net returns for watermelons, and okra, were highest when planted on clear or black mulches, with or without row covers. The authors reported that tomatoes were only profitable when planted on clear or black mulch with row covers. The use of plastics increased crop earliness, and stimulated plant growth, while planting on bare soil resulted in late maturation which typically results in harvests when market prices are declining.

Ernst (2020) discussed high tunnel economics. He indicated that the profitability of TH compared to open field production of crops depends on the yield/ (sqrt. ft. of space), higher market prices for produce grown out of season, higher quality of vegetables, and a higher volume of marketable yield. According to him, additional factors which can affect the success of TH production include the different types of crops growers may choose, the amount of labor required for weed control, unexpected pest and disease problems, and the activities of rodents and other wildlife, which may prefer the comfort of a TH in winter. Other important factors include the buildup of certain soilborne pests and diseases (due to the absence of crop rotation), the accumulation of salts in the soil due to rainfall leaching of fertilizers, and day length.

Galinato (2012) also examined enterprise budgets of producing tomatoes in THs in Western Washington State. He showed that TH-produced tomatoes cost $15.41 sqrt. /ft. compared to .61/ sqrt. /ft. for field-grown tomatoes. However, the market price received was $3.00/lb. for TH-produced tomatoes which netted $11.59 sqrt. /ft. while the field-grown tomatoes netted only $1.49 sqrt. /ft. The higher returns for TH-produced tomatoes were due to the yield of 9 lbs./sqrt. /ft. throughout the season compared to field-grown tomatoes which produced .7lbs./sqrt/ft. Fischbach (2020) also reported that the seasonal yield of TH spinach in Wisconsin ranged from 1.3 lbs. to .3 lbs. sqrt. /ft. but overall averaged 1.0 lb. sqrt. /ft. This difference in yield depended on the weather conditions at the time of planting.

Galinato and Miles (2013) reported that TH-grown tomatoes and lettuce in western Washington state were five to eight times more expensive to produce compared to field-grown counterparts. However, lettuce and tomatoes produced in TH had three to four times more marketable yield. Based on the current market prices and yield, they concluded that it was more profitable to grow lettuce in the field and tomatoes in THs. Kaiser and Ernst (2017) estimated that TH production and marketing costs for mixed greens produced in Kentucky were $440 and $500, respectively, on 0.5 acres. According to the authors, factoring in depreciation costs brought annual expenses for the growing of leafy vegetables to $1,440. They conservatively estimated that producers can expect a net return to land, capital, and management of $1,556 from a gross income of $3,000.

Materials and Methods

Tunnel House and Soil Type

This study was conducted during the fall-winter of 2018-19 in a Wiregrass TH of 960 total Sq. ft. with 826 sq. ft. of planting space, located at S & B Farm in Eufaula, Alabama. This TH is made from wood or metal, polyethylene pipes, and covered with clear greenhouse plastic film without any supplemental heat or cooling. All planting was done directly in the soil and not on raised beds or containers.

The soil type at the study site was classified as Norfolk sandy loam (fine, siliceous, thermic Typic, Paleudults), but was later reclassified as Kinston fine-sandy loam (fine loamy, siliceous, semiactive, acid, thermic Fluvaquentic Endoaquepts) (USDA, 2004).

Tunnel House Site Preparation

The site was tilled with a mechanical rototiller prior to the manual preparation of rows. At the time of row preparation, an NPK (13-13-13) mix of fertilizer was banded in single and staggered plots at the same rate, based on soil test recommendations. All rows were orientated in a North/South direction. Plastic tube drip irrigation lines (Chapin Drip Tape) were placed in the center of each row to provide irrigation water to the plants. All plots were drip irrigated for three hours every other day until the end of the study at 171 days after transplanting (DAT) based on the methods described by Khan et al. (1994).

Experimental Planting Materials

Transplants of "Hi-Crop Hybrid" and "Georgia-Collards", were raised in plug trays in the greenhouse, and transplanted at six weeks old onto single and staggered plots (Figure 1) that were 14' long and spaced at either 16" or 24" apart. Collards were transplanted 12 inches apart within rows, giving a total of 14 and 27 plants for single and staggered rows, respectively. Weed growth between rows was manually controlled.

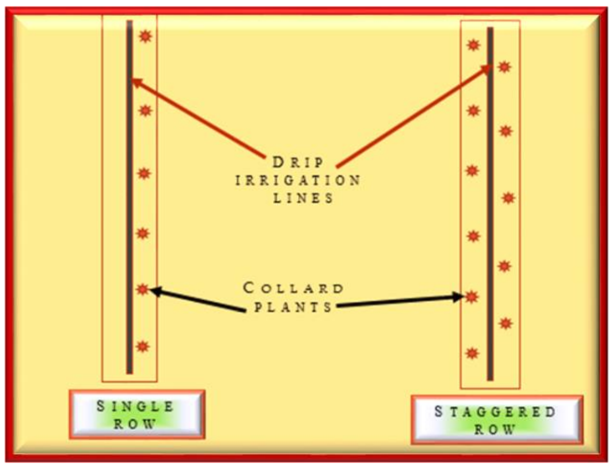

Figure 1. Single and Staggered Row Pattern of Planting Collards

Field Experimental Design and Data Collection

All plots were arranged into a randomized split-split-plot design with three replications per treatment (Snedecor, 1966). The main plots comprised 6 harvest periods: 45, 66, 87, 108, 129, and 150 DAT. Subplots consisted of single and staggered planted rows of "Hi-Crop Hybrid", and "Georgia-Collards" inter-spaced at 18 and 24 inches, at an intra-spaced distance of 12 inches apart for both row patterns. At each harvest period, all of the leaves present on each plant in each treatment were counted, and 50% of them were then harvested starting from the bottom whorls. The numbers and weight were then recorded by treatments and replication.

Statistical Analysis and Other Calculations

Data for the number of leaves harvested were square root transformed before analysis. All yield data were extrapolated to numbers and yield per acre before being analyzed using a Factorial Analysis of Variance with mean separation by Fisher's F test (Snedecor, 1966). The chilling hours were calculated using the F model procedure described by Fraisse and Whidden (2010) and Byrne and Bacon (1992).

Also, TH yields (leaf numbers and weight) were converted to pounds per acre using equation 1:

Equation 1. $Yield\ acre = \left(Plot\ Yield * (\frac{TH\ Area}{Plot})\right) * \left((\frac{43{,}560\ sqrt.ft.}{TH\ area})\right)$

Percent leaf weight recovery for each harvest period was calculated using equation 2:

Equation 2. $\%\ Leafwt.Increases = \left(\frac{Harvest\#2,3,4,5,6 - Harvest\#1}{Harvest\#1}\right) * 100$

Harvest#1 was the constant value used while the values for harvests 2-6 were used to get the percentages for the other harvests.

Percent increases in yield from staggered rows vs. single planted rows were calculated using equation 3:

Equation 3. $\left(\frac{Yield\ from\ Staggered\ Harvest\#1,2,3,4,5,6 - Yield\ from\ Single\ Harvest\#1,2,3,4,5,6}{Yield\ from\ Single\ Harvest\#1,2,3,4,5,6}\right) * 100$

The values for harvests 2-6 were substituted in the equation to complete the analysis.

Results and Discussion

Table 1 shows the results for collard leaf weight and numbers, harvested from two varieties over six harvests. The data showed a significant interaction between the number of harvests and leaf weight, and between the number of harvests and leaf numbers. Figures 2 and 3 show that staggered planted collards at 18 or 24 inches had higher leaf weights and numbers than single planted rows at the same spacing distances. This was probably due to staggered rows having twice the number of plants and more rows compared to single planted rows. Furthermore, these interactions showed that both varieties displayed

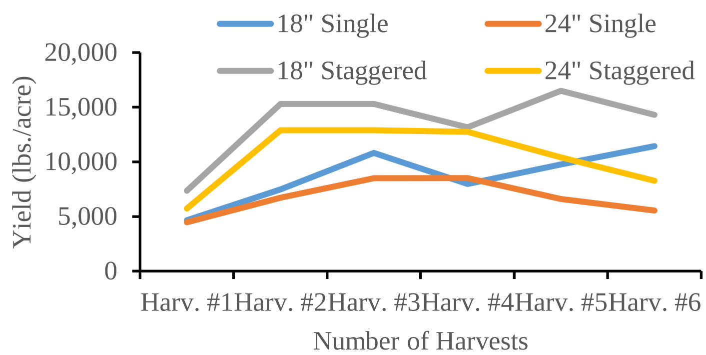

Figure 2. The Interaction Between Collard Yield (lbs./acre) For Six Harvests X Staggered/Single Planted Rows

Table 1. Mean Leaf Weight (Lbs./Acre) and Number of Leaves (Nos./Acre) from Two Varieties of Collards over Six Harvests Transplanted in Single and Staggered Pattern on Rows Interspaced at 18 and 24" Apart.

		Mean Leaf Wt. (Lbs./Acre)		
Varieties	Single 18"	Staggered 18"	Single 24"	Staggered 24"
Ga-Collards	58,318	84,744	46,810	69,216
Hi-Crop	72,590	80,501	51,134	71,460
		Mean Leaf Numbers (Nos. Acre)		
Varieties	Single 18"	Staggered 18"	Single 24"	Staggered 24"
Ga-Collards	132,560	254,703	169,110	98,905
Hi-Crop	147,033	277,790	114,020	168,789

Significance of F Test from AOV	Leaf Weight (Lbs./Acre)	Leaf Numbers (Nos./Acre)
Number of Harvests	**	**
18”/24” Staggered vs. 18/24” Single rows	**	**
Varieties	**	**
Number of harvests X Row patterns	**	**
Number of Harvests X Varieties	NS	NS
Row spacings X Varieties	NS	NS
Three-way Interaction	NS	NS

** = significant at the 1% level; NS = Not Significant

decreasing leaf weight, with increasing leaf numbers over the later harvests. This could have been influenced by the accumulation of chilling hours within the TH, and also the age of the plants. Olson and Freeman (2008) and McCormack (2005) reported that collards tended to bolt from exposure to prolonged periods of low temperatures and as the plant ages (or as it increases in size).

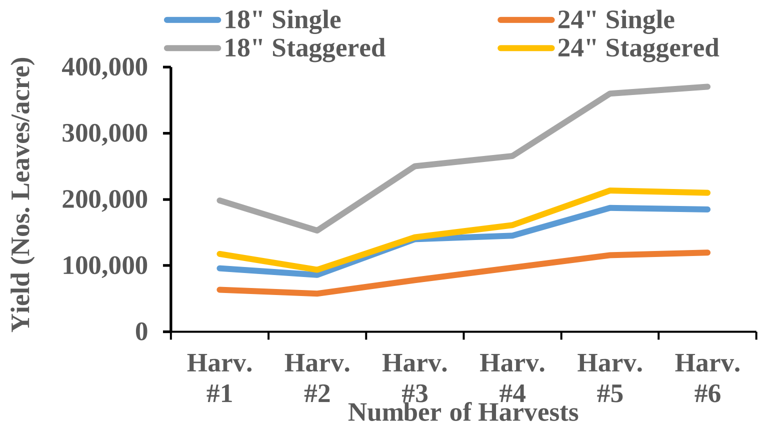

Figure 3. The Interaction Between Yield (Nos./Acre) For Six Harvest Periods X Staggered/Single Planted Rows

Furthermore, Table 1 shows that there were significant differences among varieties and single vs. staggered planting patterns. The highest yields for leaf weight and numbers were obtained at the 18” staggered and single planted rows for both varieties. The increase in leaf weight and numbers were similar to a report by Idoko et al. (2018), which stated that sesame had higher leaf area, capsule length, the number of branches, and the number of seeds per capsule at the closets of three inter-row (50, 75, and 100 cm) and intra-row (20, 30, and 40 cm) spacings. Similar results were also reported by Adigun et al. (2016); Dawuda et al. (2011), and Amjad et al. (2002), respectively, working with groundnuts, carrots, and okra, where closer row spacings had higher yields than rows spaced further apart.

Table 2. Chilling Hours Recorded Inside a Wiregrass Tunnel House During the Autumn, Winter, and Spring 2018-19 and The Age of Collard Plants at Transplanting and Each Monthly Harvest.

Months	Nos./Chilling Hours Inside Tunnel House	Cumulative Nos./Chilling Hours Inside Tunnel House	Age of Collard Plants	
			Days at Transplanting	Days at Harvest
October 31, 2018	22	22	42	-
November 30, 2018	72	94	-	77
December 31, 2018	219	313	-	98
January 31, 2019	189	502	-	121* 148
February 27, 2019	99	601	-	169
March 31, 2019	141	742	-	190
April 30, 2019	61	803	-	-

* There were two harvests in January 2019

Table 2 shows that plants were transplanted on October 2018, and chilling hours’ accumulation began to increase from November. Consequently, the combination of increased chilling hours and age of the plants, probably stimulated the plants growing on the 24” single and staggered spaced rows to bolt earlier which could account for the continued decline in yield after the third harvest for these treatments.

The number of leaves removed and the recovery rate of these leaves after each harvest determine in part the size of the succeeding harvests. Sparks et al. (2018) reported leaf recovery rates of 319% when 50% of leaves were harvested compared to 36% recovery when 100% of leaves were harvested. Also, Walton et al. (2018) reported leaf recovery rates of 319% and 277% when 50% of leaves, respectively, of "Topbunch" and "Hi-Crop Hybrid" collards, were harvested. The results from this study (Table 3) showed that there was a difference in response between the varieties and single vs. staggered row patterns. Staggered 18 and 24-inch rows of "Georgia" collards had leaf recovery rates of 225% and 185% compared to 197% and 67% for single-row

Table 3. Percent Leaf Weight (Lbs./Acre) Recovery Obtained from Staggered vs. Single Planted Rows over Six Harvests of Two Collard Varieties Transplanted on Rows Inter-Spaced at 18" and 24" in a Wiregrass Tunnel House

	Georgia Collards (%)				Hi-Crop Hybrid (%)			
Harvests	Single 18"	Staggered 18"	Single 24"	Staggered 24"	Single 18"	Staggered 18"	Single 24"	Staggered 24"
1	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
2	140	125	64	152	17	-7	39	-9
3	276	267	101	280	52	39	82	53
4	144	200	77	227	31	26	102	74
5	257	298	53	132	28	49	44	4
6	172	283	38	132	132	35	13	4
Mean	**197**	**225**	**67**	**185**	**22**	**28**	**56**	**25**
C.V %	**20**	**27**	**32**	**32**	**80**	**68**	**57**	**128**

plantings at the same inter-row spacing. "Hi-Crop Hybrid" had lower recovery rates of 28% and 25% for 18" and 24-inch staggered rows compared to 22% and 56% for single planted rows. Similar low leaf recovery rates were reported by Jackson et al. (2021), who attributed this decrease to an increase in chilling hours which predisposed the plants to early bolting. In this study, chilling hour increases were one of the contributing factors to the lower recovery rates (Table 2), and a leaf disease that resembles cabbage soft rot also contributed to the lower recovery rates. This disease affected the inner leaves of "Hi-Crop Hybrid" collards making them unmarketable. Based on the results of this and previous studies (Jackson et al. 2021; Sparks et al. 2018; Walton et al. 2018), leaf recovery rates should be equal to or exceed 100% for ensuing harvests which would provide TH producers with consistent and sustainable yields to meet market demands.

The objective for planting staggered vs. single rows was to determine if increasing the plant density could be a sustainable method to improve yield in the limited space of a TH. Table 4 shows that staggering plantings on 18" and 24" inter-space rows, respectively, increased the yield of "Georgia Collards" by 44% and 42%, and, respectively, increased the yield of "Hi-Crop-Hybrid" by 51% and 52% over single planted rows. These yield increases were achieved using the same rate of fertilizer for the single and staggered rows; however, in light of these results, the application of higher fertilizer rates should be investigated to determine if higher rates would increase the yield of the staggered planted rows. These yield increases without additional fertilizers were probably due to the lack of fertilizer leaching due to rainfall. Ernst (2020) and Blomgren and Frisch (2007) reported that the plastic roof of the TH serves as an effective barrier to rainfall; thus, preventing fertilizer run-off by rainfall.

Table 4. Mean Percent Advantage in Leaf Weight (lbs./acre) Gained from Planting Staggered vs. Single Rows of Two Collard Varieties Transplanted on Rows Inter-spaced at 18” and 24” Over Six Harvests in a Wiregrass Tunnel House

	Georgia Collards (% leaf wt. increase)		Hi-Crop Hybrid (% leaf wt. increase)	
Harvests	Staggered vs. Single 18”	Staggered vs. Single 24”	Staggered vs. Single 18”	Staggered vs. Single 24”
1	33	-10	73	93
2	25	38	38	7
3	29	70	58	47
4	64	66	57	90
5	49	36	27	31
6	63	51	51	46
Mean	**44**	**42**	**51**	**52**
C.V %	**36**	**63**	**29**	**59**

Since the data from this study showed that planting collards in a staggered row pattern increased yield, an enterprise budget was developed using a set of basic expectations such as (1) the TH actual planting space of 826 sq. ft., and the expected harvests of six commencing 45 DAT and 21 days thereafter, (2) revenue calculated on a retail price of $1.50/lb. by selling directly to the consumer, (3) average yield for each harvest of 554 and 805 lbs. for “Georgia” Collards planted at 18” in single and staggered rows, and 432 and 658 lbs. for “Georgia” Collards planted at 24” in single and staggered rows, (4) average yield for each harvest of 591 and 787 lbs. for “Hi-Crop Hybrid” Collards planted at 18” in single and staggered rows, and 486 and 679 lbs. for “Hi-Crop Hybrid” Collards planted at 24” in single and staggered rows.

The projected enterprise budget in Table 5 shows that “Hi-Crop Hybrid” had a higher net return to management than “Georgia” collards. This could be attributed to the higher yield of the “Hi-Crop Hybrid” variety irrespective of row spacing and planting pattern. However, production costs per sqrt. ft. was higher for staggered than single planted rows for both varieties. These higher growing costs were due to twice the number of plants required to plant staggered rows compared to single rows, and the increased frequency of irrigation cycles needed for growing collards on staggered rows (Figure 1). An analysis of enterprise budgets by Galinato (2012) for TH-grown tomatoes reported that it cost more to produce compared to field-grown tomatoes. However, TH tomatoes netted more income due to higher yields per sqrt. /ft. of TH space, compared to field-grown tomatoes. Similarly, in this study, staggered planted rows had higher production costs, but higher net returns per sqrt. ft. because of the higher yields per sqrt. ft. It should be noted that in this study, only 50% of the leaves from each plant were “cropped” instead of harvesting the whole plant. The combination of “cropping” only 50% of the leaves instead of harvesting the entire plant gave the ability for a high rate of leaf recovery or regrowth within 21 days after each harvest. This could be described as a sustainable production system. This practice could increase farm income for TH producers during the cool/cold season of the year when the risks of growing collards outdoors are great.

Table 5. Summarized Projected Enterprise Budget for Growing "Georgia' and Hi-crop' Hybrid Collards in Single or Staggered Rows Spaced 18" and 24" Apart in a Wiregrass Tunnel House (20' X 48')

	"Georgia Collards"			
Budget Items	Single Planted Row 18" Apart	Staggered Planted Row 18" Apart	Single Planted Row 24" Apart	Staggered Planted Row 24" Apart
Gross revenue	$4,986.00	$7,245.00	$3,888.00	$5,900.00
Production costs	$514.08	$781.99	$494.76	$758.64
Total marketing costs	$1,132.00	$1,671.47	$1,088.27	$1,501.93
Fixed costs	$85.00	$85.00	$85.00	$85.00
Interest on Capital	$207.75	$304.60	$200.16	$281.47
Total Expenses	$1,938.83	$2,843.06	$1,868.19	$2,627.04
Return to Management	**$3,047.17**	**$4,401.94**	**$2,013.00**	**$3,249.50**
Mean yield/harvest (lbs.)	**554**	**805**	**432**	**658**
Cost per Sq. ft.	**$2.34**	**$3.43**	**$2.25**	**$3.17**
Yield lbs./Sqrt./ft.	**.67**	**.97**	**.52**	**.79**
Net Returns per Sq. ft.	**$3.68**	**$5.13**	**$2.43**	**$3.95**
	"Hi-Crop Hybrid"			
Gross revenue	$5,319.00	$7,083.00	$4,374.00	$6,111.00
Production costs	$594.60	$677.70	$573.00	$677.70
Total marketing costs	$1,145.51	$1,216.07	$1,107.71	$1,177.19
Fixed costs	$85.00	$85.00	$85.00	$85.00
Interest on capital	$219.00	$237.45	$211.99	$232.79
Total expenses	$2,044.11	$2,216.22	$1,977.70	$2,172.68
Return to Management	**$3,274.89**	**$4,866.78**	**$2,396.30**	**$3,938.32**
Mean yield/harvest (lbs.)	**591**	**787**	**486**	**679**
Cost per Sq. ft.	**$2.46**	**$2.86**	**$2.38**	**$3.41**
Yield lbs./Sqrt./ft.	**.71**	**.95**	**.59**	**.82**
Net Returns per Sq. ft.	**$3.96**	**$5.69**	**$2.89**	**$3.96**

Conclusion

The results of this study have shown that when "Hi-Crop Hybrid" and "Georgia" collards are grown on staggered rows in a TH inter-spaced at 18" or 24", there are significant increases in leaf weight and numbers of the staggered "Hi-Crop Hybrid" and "Georgia" collards compared to a single planting pattern. The percent leaf weight recovery for "Georgia" collards planted on 18" staggered rows averaged 225% and 197% for single planted rows at the same spacing. At the 24" staggered spacing "Georgia" collards had a 185% leaf recovery rate compared to 67% for the single pattern. Alternatively, "Hi-Crop Hybrid" had lower recovery rates of 28% and 22%, respectively, for 18" staggered vs. single planting pattern, and 56% and 25% leaf weight increase, respectively, for the 24" single spacing compared to 25% for the staggered spacing. The low recovery leaf rates for "Hi-Crop Hybrid" was attributed to a leaf disease that affected this variety. The increase in yield resulting from planting staggered vs. single rows was, respectively, 44% and 42% for "Georgia", and for "Hi-Crop Hybrid", the increase in yield was, respectively, 51% and 52% at the 18" and 24" row spacing. The cost, yield, and net returns sqrt. /ft. for growing staggered rows at the 18" and 24" row spacing was higher than the single row pattern for both varieties. "Cropping" 50% of the total leaves from collard plants along with a high leaf recovery rate that equals or exceeds 100% of yields compared to a traditional once-over harvest, is a sustainable practice for growing collards in a THs.

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References

Abrha, H., A. Kebede, B. Amare, M. Desta. (2015). "Effect of Inter and Intra-Row Spacing on Yield and Yield Components of Tomato (*Solanum lycopersicum* Linn.) in South Tigray, Ethiopia." *Journal of Natural Sciences Research* 5 (5): 1-5.

Adigun, J.A., O.R. Adeyemi, S.T.O., Lagoke, P.M. Olorunmaiye, O.S. Daramola and A.O. Babatunde. (2017). "Influence of Inter-Row Spacing and Weed Control Methods in Groundnut (*Arachis hypogeal* (L.)." *Journal of Agriculture and Environment* 16 (1): 86-95.

Amjad, M., M. Sultan, M. A. Anjum, and C. M. Ayyub. (2002). "Response of Okra (*Abelmoschus esculentus* (L. Moench)) to Various Doses of N & P and Different Plant Spacings." *Journal of Research (Science)* 13 (1): 19-29.

Blomgren, T., and T. Frisch. (2007). *High Tunnels: Using Low-Cost Technology to Increase Yields, Improve Quality and Extend the Season*. Center for Sustainable Agriculture, University of Vermont, Burlington, Vermont.

Byrne, D. H., and T. A. Bacon. (1992). "Chilling Estimation: Its Importance and Estimation." *The Texas Horticulturist* 18 (8): 8-9.

Coolong, T. (2017). "Commercial Production and Management of Cabbage and Leafy Greens" Publication No. 1181, University of Georgia, Athens Georgia.

Dawuda, M. M., P.Y. Boateng, O.B. Hemeng, and G. Nyarko. (2011). "Growth and Yield Response of Carrot (*Daucus carota* (L.)) to Different Rates of Soil Amendments and Spacing." *Journal of Science and Technology* 31 (2): 11-20.

Ernst, M. (2020). *High Tunnel Economics*. Fact sheet No. CCD-FS-15. Cooperative Extension Services Center for Crop Diversification. University of Kentucky, Lexington Kentucky.

Fraisse, C. W., and A. Whidden. (2010). *Chill Accumulation Monitoring and Forecasting*. Extension Bulletin No. AE452. IFAS Extension, University of Florida, Gainesville Florida.

Fischbach, J. (2020). *Winter High Tunnel Spinach Production a Guide for Commercial and Home Grower*. Cooperative Extension, University of Wisconsin, Madison, Wisconsin.

Galinato S. P., and C. A. Miles. (2013). "Economic Profitability of Growing Lettuce and Tomato in Western Washington under High Tunnel and Open-field Production Systems." *HorTechnology* 23 (4): 453-461.

Galinato, S. P. (2012). *2011 Cost Estimates of Producing High-Tunnel Tomatoes in Western Washington*. Fact Sheet No. FS090E. Cooperative Extension, Washington State University, Pullman, Washington
Washington.

Gebremariam, G., and F. Baraki. (2018). "Effect of Inter Row and Intra Row Spacing on Yield and Yield Components of Mung Bean (Vigna radiata L.) in Northern Ethiopia." *International Journal of Engineering Development and Research* 6 (1): 2321-9939.

Ghent, P. N. (1990). "Early Tomato Production in Unheated Polyethylene Hoop Houses in Connecticut: Effects of Air and soil Temperatures." *National Agricultural Plastics Congress* 22: 135-140.

Idoko, J.A., P. D. Baba, and T. R. Ugoo. 2(018). "Effect of Inter-Row and Intra-Row Spacing on the Growth and Yield of Sesame (*Sesamum indicum* L.) in Makurdi, Nigeria." *International Journal of Agronomy and Agricultural Research* 12 (1): 69-76.

Jackson, T., R. Shange, M. Norris, C. Searight, M. S. Foo, V. Khan, J. E. Currington, E. Sparks, R. Ankumah, N. Ellison, G. X. Hunter, and J. Moore. (2021) "The Effect of a Fifty Percent Leaf Harvest from Three Varieties of Collards (*Brassica Oleracea*(L)/Cultivar Group Acephala) Cropped at Selected Intervals When Grown in A Wiregrass Tunnel House." *Professional Agricultural Workers Journal* 7 (2): 11-25.

Kaiser, C., and M. Ernst. (2017). *High Tunnel Leafy Greens and Herbs*. Publication No. CCD-CP-60. Cooperative Extension Center for Crop Diversification, University of Kentucky, Lexington, Kentucky.

Khan, V.A., C. Stevens, M. A. Wilson, D. J Collins, J.Y. Lu, and E.G Rhoden. (1994). "Walk-in-Tunnels as an Alternative Method of Extending the Growing Season for Small Scale Vegetable Producers in Alabama." *American Society for Plasticulture* 25: 117-121.

Khan, V. A., C. Stevens, J. Y. Lu, C. K. Bonsi, A. T. G. Siaway, G. M. Paris, M. A. Wilson, and J. E. Brown. (1989). *Capturing Early Markets by using Agriplastics Total Costs and Net Returns for Watermelons, Okra, and Tomato Grown Under VisPore Row Cover and Two Types of Polyethylene Mulch Planting Systems*. Publication No. 108-194., George Washington Carver Agricultural Experiment Station and Cooperative Extension Service, Tuskegee University, Tuskegee, Alabama.

Madisa, M., E. T. Mathowa, C. Mpofu, and T. A. Oganne. (2015). "Effects of Plant Spacing on the Growth, Yield and Yield Components of Okra (*Abelmoschus esculentus* L.) in Botswana." *American Journal of Experimental Agriculture* 6 (1): 7-14.

Masa, M., T. Tana, and A. Ahmed. (2017). "Effect of Plant Spacing on Yield and Yield Related Traits of Common Bean (*Phaseolus vulgaris* L.) Varieties at Areka, Southern Ethiopia." *Journal Plant Biol Soil Health* 4 (2): 13.

McCormack, J. H. (2005). "Brassica Seed Production: An Organic Seed Production Manual for seed Growers in the Mid-Atlantic and Southern US." *Version* 1.1: 1-24.

Olson, S. M., and J. H. Freeman. (2008). "Collard Evaluation in North Florida." *HortTechnology* 18 (3): 536-538.

Sanders, D. (2001). *Collards Horticultural Information Leaflet*. NC State Extension Publications, North Carolina A&T State University Greensboro, North Carolina.

Sharp, R. (2008). *Agriculture and Business Management*. Cooperative Extension, Colorado State University, Fort Collins, Colorado.

Snedecor, W.G. (1966). *Statistical Methods*. Ames, Iowa: Iowa State University Press.

Sparks, Edward; R. Shange J. Jackson, V. Khan, J. E. Currington, R. Ankumah, N. Ellison, G. X. Hunter Jr., and J. L. Moore. (2018). “The Evaluation of Two Different Harvesting 'Topbunch' and 'Hi-Crop' Collards (Brassica Oleracea (L)) Leaves from Plants Grown in a Wiregrass Tunnel House.” *Professional Agricultural Workers Journal* 6 (1): 64-72.

USDA NRCS. (2014). *Planting in a High Tunnel*. USDA NRCS, Washington D.C.

USDA. (2004). *Soil Survey Manual, Handbook 19*. U.S. Department of Agriculture, Washington, DC.

Walton, V. E., R. Shange, M. Johnson, E. Sparks, V. Khan, J. E. Currington, R. Ankumah, N. Ellison, G. X. Hunter Jr., and J. L. Moore. (2018) “The Effect of Two Different Harvesting Methods on the Yield of 'Topbunch' and 'Hi-Crop' Collards (Brassica Oleracea (L)) When Grown in a Wiregrass Tunnel House.”*Professional Agricultural Workers Journal* 6 (1): 51-63.

Wells, O. S. (1993). “High Tunnels for Early Spring or Late Fall Production of Tomatoes and Other Crops.” *Proceedings American Society of Plasticulture* 24: 76-82.