SEASON EXTENSION USING SUPPLEMENTAL SOIL HEAT IN A NORTH DAKOTA HIGH TUNNEL FOR WARM SEASON VEGETABLE PRODUCTION

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Plant Sciences

November 2021

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Vegetable production options in North Dakota are limited by environmental challenges. Combining soil heating cables and row covers within a high tunnel could protect crops from frost, extending the growing season. Three planting dates at three-week intervals, low tunnel coverings (clear plastic, light frost blanket, and heavy frost blanket), and supplemental soil heating (untreated and soil heating coils) were examined in Absaraka, ND for the effects on two basil and two snap bean cultivars. Soil heating cables increased cumulative harvested basil height by 20% over the untreated control in 2018, but not 2019. Overall, early basil plantings provided the greatest cumulative yield, with ‘Eleonora’ benefiting most from early planting. Cumulative bean yields were significantly increased with early plantings. However, soil heating and covers did not significantly affect cumulative bean yield in either year. Results indicate that in North Dakota, soil heating can increase yields with early plantings and appropriate cultivars.

ACKNOWLEDGMENTS

First of all, I would like to express my sincere gratitude to my advisor Dr. Harlene Hatterman-Valenti for the continuous support throughout my M.S. journey. I could not have asked for a better advisor and a mentor. Thank you for believing in me. As I always say, you are the best. Further, I give special thanks to my graduate research committee members, Dr. R. Jay Goos and Dr. Chiwon Lee, for your encouragement, insightful comments, and questions.

My sincere thanks go to Collin Auwarter for your continuous support and guidance throughout my research and fieldwork. A special thanks to my fellow lab mates, Andrej Svyantek, Matthew Brooke, Ryan Archer, and all the HVC crew for your assistance during this project. I could have never done it without you all. I am grateful to Dr. Jawahar Jyoti and Avery Shikanai for your help with the statistics. I would also like to acknowledge North Dakota State Specialty Block Grant for funding this project. Finally, I am also thankful to all the helping hands for the direct and indirect support throughout my research journey.

Last but not least, I would like to thank my family, my parents Krishna Rana and Ambika Rana, for all the sacrifices, unconditional love, and faith throughout my life.

DEDICATION

I dedicate this thesis to my parents Krishna Rana and Ambika Rana, my little brother Binamra Rana and Sailesh Sigdel for all the love, support, and strong faith.

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INTRODUCTION

Globally, vegetables are considered to be protective foods because they are rich in vitamins, minerals, color pigments, and antioxidants, as well as providing sustenance, nutrition, and livelihood security (Weisburger, 1999; WHO, 2003; Schreinemachers et al. 2018). In addition, the rise in urban populations and increased incomes are creating a surge in consumer demand as consumers try to diversify their diets (Schreinemachers et al., 2018). To meet this growing demand, increasing vegetable production is an important economic opportunity. According to Food and Agriculture Organization of United Nations, vegetable production in the U.S. ranks third worldwide after China and India (2021). The U. S. produced 61.1 million Mt of commercial vegetables ((including mushrooms and potatoes, (*Solanum tuberosum* L.)) during 2020, with a value of over $19.6 billion and harvested area of about 2.7 million hectares (Davis et.al, 2021). Fresh vegetables are increasingly in demand in the U.S., with consumer demand likely to continue rising. Such increasing demand creates a great economic opportunity for the large-scale industry and small-scale local growers across the nation. Furthermore, national data shows that demand for locally produced food has been on the rise for several years.

Unpredictable events, such as the COVID-19 pandemic, have resulted in increasing skepticism about the safety of the large-scale food production industry. Consumers are now looking for meat and vegetables grown locally. The demand for locally grown vegetables provides an important economic opportunity to local growers, as vegetables typically offer more profits and employment per hectare than cereals crops (Joosten et al., 2015).

However, northern climates with a limited growing season have fewer options for vegetable production due to seasonal and regional differences. In addition, changing climate and associated changes in frequency, intensity, and duration of extreme climatic events has impacted and will continue to affect regional vegetable production (Kirezieva et al., 2015). Besides this, the technologies used and practices followed for organic vegetable farming are primarily conventional, resulting in low yield, less productivity, and inconsistent produce quality (Wells et al., 2000). In recent decades, the growing demand for off-season and high-quality vegetables has prompted local farmers to focus on modern cultivation methods in response to the increasing off-season and high-quality vegetable markets (Kläring, 2001). In this context, protected agriculture is gaining momentum to enhance total yield and quality improvement, a major problem of vegetables grown in open field conditions, especially in extreme climatic conditions. Temperature fluctuations limit year-round outdoor vegetable cultivation. Protected structures like row covers, high tunnels, and greenhouses modify these extremes, enabling vegetable production almost year-round by altering the environment either in the soil temperature of the root zone or in the air temperature surrounding the plant. Thus, using a protected structure for vegetable production can increase crop yields, extend growing seasons, and produce crops all year round, depending on regions (Jensen and Malter, 1995). Moreover, horticultural crops producers, researchers, and extension specialists in the U. S. are increasingly recognizing high tunnels as valuable tools for manipulating the growing temperatures to stay within the optimum temperature range and assist with season extension and crop protection (Carey et al., 2009).

Previous research has shown that high tunnel use has successfully helped to extend the production window of several high-value crops in cold or high elevation climates (Waterer, 2003; Rowley et al., 2010; Hunter et al., 2012). So, in regions like North Dakota, where the growing season is short and adverse climatic conditions are limitations for vegetable production, the use of high tunnels can extend production and improve vegetable productivity early and late in the season (Rader and Karlsson, 2006).

Early-spring and late-fall temperature extremes and the chilling temperature in North Dakota have always been a matter of concern among high tunnel growers, due to the commercial production limitations for the various warm-season crops. During the early and late winter period, cold air and soil temperatures along with seasonal changes in light intensity and amount become the main limiting factors affecting crop performance in high tunnels (Drost et al., 2017). In addition to low temperatures, high tunnels experience large diurnal temperature fluctuations during the early spring and late fall. In such a case, secondary covers and supplemental heat are required to increase the temperature around plants beyond what the high tunnels alone can achieve (Drost et al., 2017). In conjunction with a high tunnel, secondary covers and additional heat sources may afford plants with added protection, increasing the amount of time spent near their optimal temperature range (Hunter et al., 2012). For instance, several researchers have shown that an additional layer of plastic or fabric can increase air temperature adjacent to plants by 5 to 10 °C on sunny days and 3 to 5 °C at night (Wells and Loy, 1985; Waterer, 2003; Wien et al., 2006; Lamont, 2009). Borrelli et al. (2013) also stated that it is important to regulate extreme temperature fluctuations to maintain consistent growing conditions for vegetables throughout the winter. They suggested that row covers and supplemental heating can be used inside high tunnels to enhance crop growth when additional heat or insulation is necessary. Therefore, suitable row covers and supplemental heating must be assessed to identify viable management strategies that regulate extreme temperature fluctuations to maintain consistent growing conditions for vegetables throughout the early spring and late fall growing conditions in North Dakota.

The objectives of this project were i) to determine whether a high tunnel in North Dakota will be able to extend the growing season for warm-season crops and ii) determine the ability of supplemental heat sources (heating cable and row covers) to provide temperature protection for early-planted warm-season vegetables.

Literature Review

Protected agriculture

Protected agriculture modifies the growing environment through technology to extend the growing season and improve vegetable yields and quality. Dr. E.M. Emmert was a pioneer in developing plastic-covered greenhouses to produce vegetables at the University of Kentucky and is credited as the "Father of Plasticulture" in the United States (Lamont, 2005). Dr. Emmert's early designs were constructed using crude wooden frames covered with stretched cellophane and supported by wire. When polyethylene became available in the early 1950s, he built the first plastic-covered greenhouse in 1953 in Kentucky. During this period, university scientists and industry partners conducted a great deal of research on improving the quality of plastic covers, analyzing the use of double layers for energy conservation, and improving ventilation and heating systems (Lamont, 2005). Since then, protected agriculture has increased in popularity as a way to increase yield and improve crop quality, major concerns of vegetable growers in continental regions. Over time, the new protected agriculture tools have continually improved. Protected agriculture implies modifying the environment either within the root zone, or the air temperature surrounding the plants by using different tools ranging from mulch, drip tape, row covers, high tunnels, hydroponics, greenhouses, etc. The ultimate goal of using protected agriculture is to increase the crop yield, protect from insects and diseases, extend the growing period and grow quality crops all year round (Jensen and Malter, 1995).

High tunnels

High tunnels are semi-permanent structures that look like a greenhouse, but they are covered with polyethylene plastic and supported by arch ribs driven into the ground (Waterer, 2003). Though high tunnels incorporate some basic concepts of a greenhouse, such as providing a milder microenvironment to the crops, protection from insects, rain, and extending growing seasons, the management and precision in environmental control differ considerably.

High tunnels (also called “hoop houses”) are temporary structures and significantly reduce operating costs compared to traditional greenhouses. These systems require lower capital investments, creating a low barrier to entry to new growers (Wells and Loy, 1993). High tunnels fit somewhere in between the low tunnels (single rows with a cover) and greenhouses (Wells and Loy, 1993) with respect to cost and control over the growing conditions.

High tunnels use solar energy to increase their internal temperature. Short-wave radiation from the sun enters the high tunnel, where plants and soil absorb it. Heat dissipates from plants and soil covered as conduction, convection, or long-wave radiation which cannot pass through the plastic. As a result, the air temperature in a tunnel rises, resulting in as much as a 30° C increase in air temperature during the day above the ambient outside temperature. (Wien et al., 2006). In this way, high tunnels facilitate plant growth by increasing and buffering growing temperatures. Although much of the accumulated heat dissipates after sunset, the air within the high tunnels can remain 1 to 3 degrees warmer than the surrounding environment during the night. As a result, the growing season extends earlier into spring and later into fall due to daily temperature increases. Regions like the Northern Plains, which includes North Dakota, where extreme diurnal temperature fluctuations limit the growing season, are particularly well suited for high tunnel use. The energy stored during the day will allow tunnel temperatures to remain above freezing during the night. High tunnels not only extend the growing season through the entire winter by temperature modification (Hunter et al., 2012), it also helps to improve crop/fruit quality, increasing production by 2-3 times per unit area (Lamont, 1996), increasing nutrient uptake, and providing some climactic control such as protection from rain, wind, and hail compared to conventional production (Hodges and Brandle, 1996). For instance, Retamal-Selgado et al. (2015) showed that a high tunnel constructed with a single layer of plastic increased night-time minimum temperatures by 2 °C at the height of 1.2 meters above the ground, which allowed blueberries to be harvested 14 days earlier with a 44 % increase in blueberry yields.

High tunnels may also deter insect, pests and animals that damage crops and transmit diseases. As a result, it reduces the need of fungicide and pesticide applications, which ultimately contributes to a more sustainable production system. According to Lamont et al. (2003), vegetables that have been grown successfully in high tunnels includes broccoli (*Brassica oleracea* var. *italic* L.), cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*), cucumber (*Cucumis sativus* L.), eggplant (*Solanum melongena* L.), kale (*Brassica oleracea* var. *acephala*), kohlrabi (*Brassica oleracea* var. *gongylodes*), lettuce (*Lactuca sativa* L.), muskmelon (*Cucumis melo* L.), okra [*Abelmoschus esculentus* (L.) Moench], onion (*Allium cepa* L.), pepper (*Capsicum annuum* L.), spinach (*Spinacia oleracea* L.), summer squash (*Cucurbita pepo* L.), Swiss chard (*Beta vulgaris* L. var. *cicla*), and tomato (*Lycopersicon esculentum* Mill.). With such a range of vegetables and high tunnel benefits, growers can access new markets for new crops with a longer market window at favorable prices (Wells and Loy, 1993). As a result, multiple research and extension programs are currently dedicated to exploring a range of possible high tunnel crops with potential for season extension (Carey et al., 2009).In addition, high tunnels' low construction and operating costs enable the producers to recover their investment within one or two years (Blomgren and Frisch, 2007).

Although high tunnels are covered with polyethylene plastic, temperature variation may occur within high tunnels and during extreme temperature events/days in early spring and late fall. For example, temperatures on the edge of a 10 m wide tunnel were 1 to 2 °C cooler than the center (Wein, 2009). Wein also reported that temperatures might also fall below outside temperatures depending on the transparency of the greenhouse plastic material to IR radiation. Row covers and minimal soil heating can be used in high tunnels to protect against extreme temperature fluctuations. (Lamont, 2005).

Temperature modification within high tunnels

A strategy to help plants survive freezing temperatures early in the season and late in fall within a high tunnel is to have supplemental heat sources such as soil heating cables and row covers. Borrelli et.al, (2013) suggested that the high tunnels can be equipped with low tunnels or row covers to enhance crop growth in locations where additional heat or insulation is required. Combining soil heating cables and row covers within a high tunnel further enhances temperature protection by trapping warm air and longwave radiation closer to the plants. (Wells and Loy, 1993).

Soil heating cables

Soil temperature has a significant effect on seed germination percentage and emergence time. The use of soil heating cables keeps the soil warm and helps accelerate the germination of seeds and growth of the seedlings. Soil heating is more energy-efficient and has been shown to offset the adverse effects of low air temperature (Janes and Mcavoy, 1983). Experiments by Drost et al., 2017 showed significant increases in soil temperature due to heating cables. Still, they were most notable late in the fall and early in the winter when soil temperatures were the lowest. Soil heating was shown to increase biomass accumulation and nutrient uptake for many crops in greenhouse environments (Shedlosky and White, 1987). Secondary covers and soil heating were beneficial when trying to hasten the production of a warm-season crop such as tomato to capture early-season yield and premium pricing (Hunter et al., 2012). Supplemental heating cables are therefore of interest to aid in cold temperature protection during the early season. There is also a need to evaluate whether soil heating maintains the effectiveness of high tunnels to grow off-season vegetables and could be profitable for North Dakota growers.

Row covers

Row covers are the flexible, transparent materials generally made of polyethylene, polyester, or propylene that is hoop supported or floated over a row or rows of crops after direct seed planting or transplanting to increase the day temperature and promote growth (Wells, O.S. 1996). According to Drost et al. 2017, in contrast to uncovered controls, ambient air and soil temperatures were significantly higher under covers during the day and at night. Hoop-supported row covers with polyethylene are also known as low tunnels (Wells and Loy, 1993), which resemble the miniature form of the high tunnels. The covers are supported with the hoops because when they rest directly on the plants, the tiny space between the plants and the covering materials provides a less favorable environment for plant growth than covers stretched over a frame (Hanada, T. 1991). The row covers are used to increase the protection from frost and retain heat within each respective row, and researches have shown an improvement in productivity for certain crops with the use of row covers (Gerber et al., 1988; Wells and Loy, 1993). Borrelli et al., (2013) suggested that a low tunnel or row cover should be set up within high tunnels to increase crop growth when additional heat or insulation is needed. Both can increase temperatures from 2 to 6°C, and polyethylene row covers, when used alone, were shown to protect tomato plants from frost when the outside temperatures were –3.8 °C (Emmert, 1956). The other type of row cover is the spun-bonded cover, made by polypropylene, also called the floating cover or cover cloth, which is breathable compared to the polyethylene tunnels. According to Mukherjee et al., (2019), polypropylene also can serve as the best method for pest exclusion. The floating row covers can be placed directly above the plants with the help of an arch; however, on windy days, the flapping of the cover may cause injury to the crops. These types of covers perform best when the soil is warm, but during handling, the fabric of spun bonded covers weakens and tears, deterring continued use. (Wells and Loy, 1993). The row covers are used for 2-4 weeks in the spring or longer in the fall or winter when the temperature is low (Wells and Loy, 1993). They also have the potential to increase early harvest by creating a mini-greenhouse effect. (Lamont, 1996). The row covers also play a vital role in protecting the crops from insects and insect-transmitted diseases by providing a barrier between the insects and the crops (Duchesne, 1990). However, essential factors such as how planting dates and varietal selection also affect seasonal and cumulative yield patterns have not been researched in the northern U.S. regions (Kinet and Peet, 1997).

There is a need to evaluate whether soil heating cables, covering and maintaining high tunnels' effectiveness to grow off-season vegetables, could be a profitable implement for North Dakota growers.

Factors affecting production in high tunnels

Cultivar selection

Vegetables are bred to grow in a variety of climates and growing conditions. Cultivar selection remains a critical component to crop production, and many important traits contribute to cultivar performance in all growing environments, including high tunnels. For example, some tomato cultivars will produce a crop in less than two months, while others take more than three months of hot weather to produce ripe fruit. Crops differ among cultivars in their response to different light and fertilizer levels (Conover and Flhor, 1997). In addition, consumer preferences (taste), marketable yield, and yield components such as the percentage of unmarketable fruit and the total number of fruits are relevant to growers. Peterson and Taber (1991) observed significant differences among cultivars in the number of flowers when tomato plants were grown using fabric row covers. For instance, tomato cultivars for outdoor production had more leaf area than desirable compared to plants grown in high tunnels (Saglam and Yazgan, 2000). In a protected growing area such as a high tunnel, greater leaf area can promote fungal diseases within the plant’s foliage due to moisture retention and lack of air movement (Saglam and Yazgan, 2000). It is also important to include other traits, such as disease susceptibility and physiological disorders, in assessing the overall performance of a cultivar (Hutton and Handley, 2006).

Planting date

Planting dates are one of the most important decisions to make when growing vegetables. For example, in Connecticut, tomatoes transplanted into tunnels on May 1 ripened three weeks earlier than tomatoes planted into the field on the same date (Gent, 1991). Gent also reported that tomatoes transplanted into high tunnels on April 3 ripened 13 days earlier than plants transplanted into tunnels on April 17. This suggests that early planting benefits under a protected structure are due to accelerated maturity (Gent, 1991; Waterer, 1993). Furthermore, Waterer (1993) suggested that rapid crop development is vital for greater total productivity in the regions with a short growing season. He also observed that without row covers' protection structure, early planting reduced yields of mature fruits in the short growing season typical of the Canadian

Prairies. This suggests that increased exposure to adverse conditions associated with early planting may negatively affect non-protected crops. Hunter et al., (2012) also reported a trend for a decrease in total yield for tomatoes as planting dates were delayed in Utah. Therefore, choosing the right planting date and utilizing row covers are essential for yield and economic benefit under commercial conditions.

High Tunnel Vegetable Production in North Dakota

High tunnels are the unheated structures used for the season extension, which allows the temperate region's growers to fulfill the off-season consumer demand for fresh market produce (Conner et al., 2009). Yet, their use is expected to be further exploited by North Dakota growers, especially in early spring and late fall. The extreme climate of North Dakota presents benefits and challenges regarding high tunnel production. During winter in North Dakota, the chilling temperature has always been a matter of concern among growers, mainly because it limits the commercial production of the various warm-season crops. In addition, the average time between the last and first frost in North Dakota is 130 days, which is a minimal farming window (Urban Farmers, 2021). One strategy for helping plants survive freezing temperatures in a high tunnel early and late in the season is to have supplemental heating cables, row covers, plastic mulches, or a combination of all. When employed on a wide scale, this may be incredibly effective. Still, it may also be costly. Root zone heating is more energy-efficient and was shown to offset the adverse effects of low air temperatures (Gosselin and Trudel, 1985; Janes and Mcavoy, 1983). If a heat source could protect plants from sporadic freezing temperatures at night, the average frost-free period would increase dramatically.

Overall, this thesis seeks to determine whether high tunnels can significantly extend the warm season growing season and whether the use of additional heat sources can protect against frost damage in North Dakota.

MATERIAL AND METHODS

Site Description and Preparation

The study was conducted at the NDSU Dale E. Herman Horticulture Research and Arboretum farm (HRA) during the 2018 and 2019 growing seasons near Absaraka, North Dakota, in Cass County (46°59’28.2” N 97°21’19.9” W, 1070 m elevation). This site is classified as USDA hardiness zone 4a (USDA-ARS, 2012). The region is considered continental, with hot and dry summers and cold winters with frost temperatures (Tollerud et al., 2018). Precipitation averages 380 to 760 millimeters per year from northwest to southeast (HPRCC, 2018). On average, Absaraka experiences 139 frost-free days with the average last and first frost dates of May 10th and Sept. 26th, respectively (National Oceanic and Atmospheric Administration, 2013). The soil type belongs to the Warsing soil series; Fine-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Oxyaqic Hapludolls. Warsing soils are composed of moderately well-drained loam alluvium over stratified sand and gravel. (Soil Survey Staff, 2000).

A high tunnel approximately 29 m long, 9 m wide, and 5 m tall was built in a gothic style with 13-gauge galvanized steel supports and a double layer of 6-mil clear polyethylene film (Northpoint, Rimol Greenhouse Systems, Inc. Hooksett, NH), with a north-south orientation. Further, the structure was strengthened by nominally framed end walls, baseboards, and hip boards. The inside temperature of the high tunnel was maintained at 25-30 ºC during the growing season with side wall rollups that automatically raised when the temperature for the electrical thermostat at the height of 4 m inside the tunnel exceeded 24 °C as they were connected. The sidewalls were raised manually during periods of high winds. The high tunnel had a garage door on both the end walls that were manually opened to provide additional ventilation during hot days. Before planting or transplanting, beds were tilled using a rototiller. Beds were 4.8 m long and 1.2 m wide and contained a single row of plants within a row, plants were spaced 30 cm apart. Each bed was irrigated with a single line of 15-mil drip tape (Toro® Aqua Traxx, Drip Works, Willits, CA) with emitters spaced 20.3 cm apart. Irrigation using the drip tape (1.29 L min^{-1}) was scheduled approximately every other day for two hours. Hand weeding was done as needed.

Plant Materials

The crops selected for the study were basil (*Ocimum basilicum*) and snap bean (*Phaseolus vulgaris*). Two cultivars for basil: Eleonora and Everleaf, and two cultivars for bean: Amethyst Purple and E-Z pick, were selected (Johnny's Selected Seeds Winslow, ME) with slight plant characteristic differences (Table 1).

Table 1. Basil and bean cultivar, characteristics (days to maturity, fruit size, and color) according to Johnny's selected seed (2021).

Species	Cultivar	Disease Resistance^{Z}	Days to maturity ^{Y}	Color
Basil	Eleonora	DM	65	Glossy green
Basil	Everleaf	FW	74	Glossy green
Bean	Amethyst Purple	BMV	56	Purple
Bean	E-Z pick	BMV	55	Green

^{Z}DM= Downy Mildew, FW= Fusarium Wilt, BMV= Bean Mosaic Virus

^{Y} Days to maturity is the days from seeding/transplant to the first harvestable fruit.

Plant Establishment and Planting date

To start the basil seed in the North Dakota State University Greenhouse, 72-cell insert plug trays (T.O. Plastics, Clearwater, MN) filled with a growing medium PRO-MIX FLX (Premier Horticulture Inc., Quakertown, PA) (Premier Peat Co. (75-85% peat by volume, perlite, vermiculite, macro-, and micronutrients and wetting agent)) were used. We started the basil seeding indoors on 2 Mar, 23 Mar and 13 Apr in 2018 and 3 Mar, 25 Mar and 15 Apr in 2019. Basil seedlings were grown at 26ºC daytime and night temperature for five weeks.

There were three planting dates: 9 Apr., 30 Apr., and 21 May in 2018 and 8 Apr., 29 Apr., and 20 May in 2019.We used 144 plants per cultivar totaling 288 plants per species. Bean seeds were seeded directly, while the basil plants were transplanted. Initially, we planted 10 seeds of beans, then thinned them out later to create a final stand of four plants with 30 cm of space between them. Basil plants were 5 weeks old when they were transplanted, and they were almost 30 cm tall. Basil plants were irrigated immediately following transplanting. A supplemental soluble fertilizer was applied via the drip irrigation system at a rate of 33.63 kg ha^{-1} N from water-soluble fertilizer (20N-20P-20K) two times during the growing season, i.e., in the month of June and July. The plants were periodically inspected for developing insect and disease issues and treated as necessary. The bean crop received an insecticide application (Capture at 621 ml ha^{-1}) for the spider mites on 20 July, 2018. Pesticides were not applied to the basil. We also staked beans by inserting 6.6 mm^2 metal wires in the ground on both ends, stretching a string down to the starting point(1st plant to last plant) , and weaving the bean plants in between the string lines to keep them upright.

Row Covers

Three row covers were examined for each crop and cultivar: clear plastic (0.8-mil), 28 g white fabric (1 oz. fabric) and 71 g white fabric (2.5 oz. fabric) (Agriculture Solutions, Strong, ME). The arches were made from the 1 m long 6.6 mm^2 metal wire bent to the shape of an upside-down U with the ends inserted in the soil to a depth of 20 cm. The bottom edges of the row covers were secured with soil. We used the row covers early in the season. They were removed by mid-May after the risk of frost was gone.

Supplemental Heat

Soil heating cables were installed following rototilling and bed preparation. Automatic water-resistant soil heating cables (Agriculture Solutions, Strong, ME) of 140 watts measuring 14.6 m in length were used. The cable made a single pass on one side of each row and was buried 2.5 cm deep with a remote soil sensor set to activate when soil temperatures dropped below 15 °C. The heating treatments were randomly assigned to 9 of the 18 rows in each replication, while the remaining rows had no supplemental heat (control).

Experimental Design and Data Collection

The air temperature at 20.3 cm above the ground and the soil temperature at 10.16 cm below ground were recorded hourly inside and outside of the high tunnel using a Decagon EM50 data logger (Decagon Devices, Inc., Pullman, WA) connected to thermistors (Decagon Devices, Inc., Pullman, WA). Soil and air temperature readings were taken as sample representatives inside three different for row covers: clear plastic cover, 28 g fabric, and the 71 g fabric at a height of 20.3 cm and at a depth of 10 cm. Other relevant meteorological data were collected from the nearby North Dakota Agricultural Weather Network station near Prosper, ND at an elevation of 284 m above sea level, 30.4 kilometers away from the HRA site.

The experiment was laid out based on the Randomized Complete Block Design with two replication (Figure A1). Each replications had 18 experimental rows further sub-divided into 4 plots consisting 4 plants each. Heat, Cover and planting were the whole plot factors whereas the cultivar was the split-plot factor. Beds were 4.8 m long and 1.2 m wide with and contained a single row of plants within a row, plants were spaced 30 cm apart.

The beans were harvested twice a week when the pods reached pencil thickness, bright green and fleshy in appearance, and before the seeds bulged. The number of pods and the weight per plant was recorded until plants were senescent and no longer productive. Basil was harvested multiple times over the season as soon as flowers became visible. Basil stems were cut almost 15 cm above ground level and allowed to regrow for another harvest. Total length of harvested stems (hereafter, height) and total harvested fresh weight were recorded at each harvest per plot. Yield data were collected at the time of harvest.

We calculated the cumulative average weight and height (hereafter, height and weight) of basil of a four-plant plot over time throughout the growing season. Similarly, for bean we calculated the cumulative average weight and number of pods (hereafter, weight and number of pods) of a four-plant plot over time throughout the growing season. Statistical analysis was performed in R version 4.1.1 (R Core Team, 2021), using the *lme4* package (Bates et al., 2015). Data were analyzed separately by year. A mixed-model of ANOVA was used to test for the effects of supplemental heat, row cover, planting date, and cultivar. The Tukey's test was used to separate means when appropriate at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The results and discussion is divided into two sections, (i) temperature modifications inside compared to outside the high tunnel and (ii) yield components for basil and bean grown in the high tunnel for two growing seasons. High tunnels in combination with the row covers and soil heating cables were used to modify the temperatures for the basil and bean crops. The results for each section are followed by the discussion, which tries to explain the impact of cover, heat, planting, cultivar, and its interaction effects on bean and basil yield and basil height for the 2018 and 2019 growing season under the high tunnel.

Air Temperature 2018

April 2018: While comparing the average daily mean temperatures, the air temperature outside the high tunnel was 4°C, while the air temperatures inside the clear plastic cover with and without heating cables was 21.8°C and 21°C, respectively (Tables 2). The temperature difference between outside the high tunnel and the clear plastic row cover with heat was almost 18°C. As compared to the high tunnel alone, the clear plastic row cover with heat provided more frost protection. However, the difference between the plastic cover with heat and without heat was only 0.5 °C (Table 2). Similarly, when comparing the 28 g cover with and without heat, the air temperature was 21 °C and 13.6 °C, resulting in a 7.4 °C increase in average temperature when using heating cables, a considerable difference. Furthermore, under the 71 g white fabric cover with and without heat, the air temperature data was interesting because the daily mean air temperature was slightly higher inside the row cover without heat, i.e., 20°C, whereas the cover with heating cables was 19.8°C. Overall, the outside daily mean air temperature was much lower than the temperature inside the row covers.

May 2018: The daily mean air temperature outside the high tunnel was 18.3°C (Table 2). The air temperatures inside the clear plastic cover with and without heat were 23.3°C and 22.5°C, respectively (Table 2). Similarly, the addition of heat cables with the 28 g fabric cover raised the average temperature from 21.9°C to 22.7°C. For the 71 g fabric row cover, we could not obtain the reading for the heat treatment because of an error in the data logger but the air temperature inside the 71 g fabric cover without heat was 23.3°C which was 5°C higher than the outside air temperature. A similar pattern was observed as compared to April where the daily mean air temperatures were higher inside the row covers than the outside air temperature, but with the increase in the outside temperatures, smaller air temperature differences occurred.

Table 2. The average daily mean air and soil temperature trend inside and outside the high tunnel and inside three different row covers in 2018 and 2019 near Absaraka, ND.

Air Temperature 2018

Month	High Tunnel	Outside HT	Plastic Cover + Heat	Plastic Cover + No heat	28 g fabric Cover+ Heat	28 g fabric Cover + No heat	71 g fabric+ Heat	71 g fabric + No Heat
April	N/A	4°C	21.8°C	21°C	21°C	13.6°C	19.8°C	20.2°C
May	N/A	18.3°C	23.3°C	22.5°C	22.7°C	21.9°C	Error N/A	23.3°C

Soil Temperature 2018

Month	High Tunnel	Outside HT	Plastic Cover + Heat	Plastic Cover + No heat	28 g fabric Cover+ Heat	28 g fabric Cover + No heat	71 g fabric+ Heat	71 g fabric + No Heat
April	N/A	N/A	N/A	N/A	19.8°C	13.1°C	N/A	N/A
May	N/A	N/A	N/A	N/A	21.8°C	18.6°C	N/A	N/A

Air Temperature 2019

Month	High Tunnel	Outside HT	Plastic Cover + Heat	Plastic Cover + No heat	28 g fabric Cover+ Heat	28 g fabric Cover + No heat	71 g fabric+ Heat	71 g fabric + No Heat
April	17.8°C	8.0°C	20°C	19.5°C	20.5°C	19.9°C	21.7°C	21.0°C
May	20.3°C	12.5°C	21.6°C	21.6°C	21.4°C	21.7°C	22.1°C	22.1°C

Soil Temperature 2019

Month	High Tunnel	Outside HT	Plastic Cover + Heat	Plastic Cover + No heat	28 g fabric Cover+ Heat	28 g fabric Cover + No heat	71 g fabric+ Heat	71 g fabric + No Heat
April	N/A	7.8°C	18.8°C	18.9°C	19.7°C	17.5°C	21.7°C	18.2°C
May	N/A	12.8°C	21.5°C	20.7°C	22.7°C	20.1°C	23.5°C	20.4°C

Soil Temperature 2018

April and May 2018: The soil temperature readings could not be processed and analysed because some of the data loggers malfunctioned. Only the soil temperatures inside the 28 g fabric cover with and without heat cables were recorded (Table 2). The only comparison that could be made was that 28 g fabric row covers with heat cables had an average soil temperature of 19.78°C, while the 28 g row cover without heat cables had an average soil temperature of 13.09°C. The heat cables raised the soil temperature inside the 28 g white fabric row cover. These results support the results of a study conducted by Dan et al., 2017, where soil temperatures were 5 to 6 °C higher with heating cables than the unheated controls.

Air Temperature 2019

April 2019: The daily mean air temperature outside the high tunnel was recorded 8°C, whereas the temperature inside the high tunnel alone was 17.8°C resulting in the increase of 9.8°C inside the high tunnel (Tables 2 and 3). Using the heat cable did not cause a substantial difference between the clear plastic cover with and without heating cables as the temperatures under the covers were 20°C and 19.5 °C, respectively. However, the temperatures were much higher when compared to the outside air temperature. The 28 g white fabric cover with and without heating cables average air temperature was 20.5°C and 19.9°C, respectively. The 71 g fabric cover with and without heating cables average air temperatures followed a similar trend of 21.7°C and 21°C, respectively and a difference of 0.7°C.

May 2019: In May, outside air temperatures were almost 4.5°C higher than April, averaging 12.5°C (Table 2). Within the high tunnel alone, the air temperature was 20.3°C (Table 2). Thus, the daily mean air temperature difference inside and outside the high tunnel was 7.8 °C. The average daily temperature inside the clear plastic cover with heating cables was 21.6°C.

Similarly, the average air temperature without heating cables was also 21.6°C, indicating no influence of the heating cables. Furthermore, the temperature readings for 28 g white fabric covers with and without heating cables were 21.4°C and 21.7°C, respectively. Under the 71 g white fabric cover, the average air temperature readings were 22.1°C and 22.1°C with and without heat cables, respectively, and again showing no difference between the two.

Soil Temperature 2019

April 2019: The outside soil temperature reached 7.8°C in April (Table 2). Similarly, both the heat-treated and unheated clear plastic covers measured 18.8°C and 18.9 °C, respectively (Table 3). The 28 g white fabric cover with heat and without heating cables had an average soil temperature of 19.7°C and 17.5°C, respectively. Likewise, the 71 g white fabric row cover with and without heating cables had an average soil temperature of 21.7°C and 18.2°C, respectively.

May 2019. As compared to April, the average daily mean outside soil temperature rose by 5°C to 12.8°C (Table 2). Heat added to the clear plastic cover increased the average air temperature to 21.5°C as compared to the unheated control which was 20.7°C (Table 3). In the same way, the 28 g white fabric cover with and without heating cables had average air temperatures of 22.7 °C and 20.1 °C, respectively. The average air temperature under the 71 g white fabric cover with and without heating cables was 23.5 °C and 20.4 °C, respectively.

As a result of the clear plastic cover acting as a tunnel within the high tunnel, sunlight entered the high tunnel and also a rise in the air and soil temperatures occurred within the clear plastic cover. Due to their low light transmission of 65% and 40% respectively (Agriculture Solutions, Strong, ME) the 28 g white fabric and 71 g white fabric did not transmit as much light as the clear plastic and had to rely exclusively on the soil heating cable. The overall trend suggested that using the row covers increased the average daily soil and air temperatures, but this was more pronounce in April compared to May as the temperature was cooler in April. Similar result was seen in the research conducted by Drost et al., (2017). They reported that although air temperatures within the high tunnel often dropped below freezing at night during the fall and winter production periods, secondary covers were able to maintain air temperatures above freezing on all but the coldest days. According to their findings, heating cables significantly increased soil temperatures in all trials, but they found that the greatest effect was seen late in the fall and early in the winter, when temperatures were lowest. Considering that the high tunnel air temperature never dropped below freezing during our experiment, planting and transplanting should have been done earlier to take full advantage of the heating cables.

Season Extension

For Prosper, ND, 30-year average data from 1981 to 2010 indicates the last frost event in spring occurs on average around 9 May, and the first frost event in fall occurs on average around 1 October. The Old Farmer's Almanac recommends planting basil and green beans in the field from 16 May - 6 June and 23 May - 13 June, respectively (2021). Harsh spring temperatures in ND make it impossible to grow warm-season crops outdoors before these dates. In 2018, the last frost event occurred 11 May, whereas in 2019, it occurred 20 May. However, we were able to plant the beans and transplant the basil in North Dakota before the recommended dates with the help of the high tunnel and the supplemental heating system. We started seeding bean and transplanting basil from the second week of April, the last week of April, and the first week of May in both years, over a 3-4 weeks earlier than the field-growing season. Similarly, for 2018 and 2019, the first frosts occurred 28 September and 10 October, respectively which occurred after the harvest was completed suggesting that a short cool-season crop could have been planted and harvested before temperatures dropped too much in the high tunnel.

Production in High Tunnel

Basil

In 2018, both the cultivars ‘Eleonora’ and ‘Everleaf’ transplanted on the first planting date (T1) were harvested on 13th July which was 95 days after the first transplanting date (T1). The ones that got transplanted on the second (T2) and third planting dates (T3) were harvested after 88 and 81 days, respectively. In 2019, basil was harvested on 25 June, 78 days after seedling transplanting. The basil were harvested till the first week of October.

Bean

Overall, in 2018, the first bean harvest occurred on 5 June, sown on the first planting date, 9 Apr. (T1). Amethyst purple was ready for harvest in 57 days, while E-Z Pick was harvested for the first time on 12 June, 64 days after sowing, which occurred before outdoor production started (June-July). Interestingly, both bean cultivars seeded on the second planting date 30 Apr. (T2) and third planting date 21 May (T3) were harvested 49 days and 50 days after seeding, which was even earlier than recommended days to maturity (55 days). The bean sown on the second and third planting dates were harvested until the end of August, whereas the bean crops seeded on the first planting date were pulled out on the second week of July because there was spider mite infestation.

Likewise, in 2019 the first harvest of beans was on 18 June for those that were sown on the first planting date 8 Apr. (T1), which means harvest occurred about 71 days after sowing. The beans planted on the second planting date 29 Apr. (T2) and the third planting date 20 May

(T3) were harvested 59 and 50 days after the seeding date, respectively. The beans were harvested until the end of August.

Basil Height

Row covers did not significantly affect total harvested basil height (Table 3). There was also no significant interaction, with the four-way interaction of row cover by heat by planting date by cultivar as the closest significant interaction in 2018 (p= 0.277). This result suggests that the transplanting dates should have been earlier, with colder air temperatures in March, so that the effectiveness of the row covers to modify air temperatures around the basil plants would have been evaluated under more extreme conditions.

Table 3. ANOVA results with the main effect of cover, heat, planting, cultivar, and interaction effect on basil yield and height for the 2018 and 2019 growing season under the high tunnel near Absaraka, ND.

Basil	2018		2019	
Source	Height[z]	Yield[y]	Height	Yield
Cover	0.528	0.684	0.100	0.923
Heat	0.037*	0.005**	0.113	0.489
Planting	0.014*	0.001***	<0.0001***	<0.001 ***
Cultivar	<0.0001 ***	0.007***	<0.0001 ***	0.678
Cover x Heat	0.320	0.271	0.703	0.747
Cover x Planting	0.714	0.656	0.873	0.930
Heat x Planting	0.330	0.036**	0.470	0.941
Cover x Cultivar	0.390	0.059	0.678	0.267
Heat x Cultivar	0.332	0.587	0.483	0.826
Planting x Cultivar	0.001**	0.019*	<0.0001 ***	<0.0001***
C x H x P[x]	0.893	0.558	0.863	0.957
C x H x V	0.414	0.202	0.438	0.441
C x P x V	0.359	0.083	0.416	0.195
H x P x V	0.033*	0.028*	0.030*	0.881
C x H x P x V	0.277	0.070	0.397	0.832

'***', '**', '*', indicates significant at $p \leq 0.001$, $p \leq 0.01$ and, $p \leq 0.05$.

[Z] Cumulative height over a growing season for a four plant plot.

[Y] Cumulative weight over a growing season for a four plant plot.

[X] Abbreviation C= cover, H= Heating cables, P= Planting date V= Cultivar.

There was a significant three-way interaction of heating cables by planting date by cultivar in 2018 and 2019 (Table 3). This resulted from the highly significant interaction of planting date by cultivar in both years (2018 $p = 0.001$, 2019 $p \leq 0.0001$), not the interaction of row cover by heating cables or the interaction of heating cables by planting date. The main effect of heating cables was significant ($p \leq 0.05$) for basil height in 2018, whereas no significant effect occurred in 2019. In 2018, the heating cable treatment resulted in greater average basil height when harvested compared with no heat treatment (Figure 1). Basil height, when averaged across levels of row cover, planting date, and cultivar, for the heat cable treatment was 600 cm, while basil harvest without the heat cable treatment had an average height of 499 cm at harvest. Thus, basil under the heat treatment had an average height that was almost 20% greater than the basil without heat.

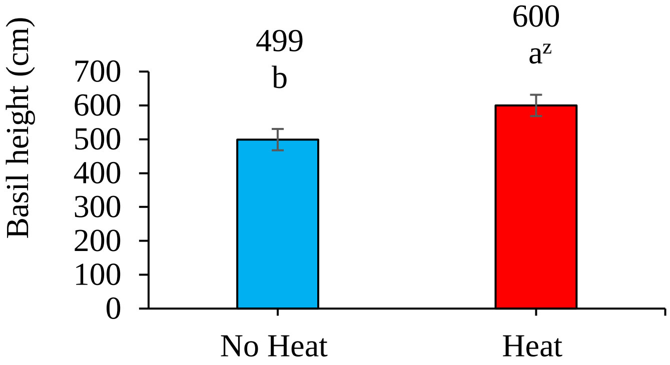

Figure 1. Effect of heat treatment on cumulative harvested basil height in a four plant plot for 2018 growing season in the high tunnel near Absaraka, ND high tunnel.
[Z] Mean values with different letters are significant for Tukey's test at α= 0.05. Error bars show standard error.

There was a significant three-way interaction of heating cables by planting date by cultivar in 2018 and 2019, which resulted from the highly significant interaction of planting date by cultivar for both years (Table 3). In 2018, the interaction occurred because basil height at harvest with 'Eleonora' decreased with successive planting dates, while with 'Everleaf' the basil height at harvest was the same regardless of the planting date. The greatest plant height (846 cm) at harvest was with ‘Eleonora’ when transplanted on the first planting date, while the lowest plant height (346 cm) at harvest with ‘Everleaf’ was when transplanted on the third planting date, which was similar to the harvest height (410 cm) with ‘Everleaf’ transplanted on the first planting date.

Table 4. The interaction of cultivar and planting date on average basil plant height at harvest in 2018 and 2019 within a high tunnel near Absaraka, ND.

Cultivar	Planting	Plant Height[Z] (cm)	
		2018	2019
Eleonora	T1 [Y]	846 a [X]	814 a
	T2	712 ab	787 a
	T3	554 bc	180 c
Everleaf	T1	410 cd	434 b
	T2	429 cd	400 b
	T3	346 d	401 b

[Z] Cumulative height over a growing season for a four plant plot.

[Y] Abbreviation T1 = first transplanting date, T2 = second transplanting date, T3 = third transplanting date.

[X] Mean values with different letters for each year indicate significant difference between planting dates and Cultivar according to Tukey’s test at α= 0.05.

In 2019, the interaction occurred because the basil height at harvest with ‘Eleonora’ again decreased with successive planting dates, while with ‘Everleaf’ the basil height at harvest was the same for the first two planting dates and then decreased for the third planting date. The greatest plant height (814 cm) at harvest was again with ‘Eleonora’ when transplanted on the first planting date, while the lowest plant height (180 cm) at harvest was again with ‘Eleonora’ when transplanted on the third planting date, but this harvest height was significantly less than the ‘Everleaf’ harvest heights transplanted on all three planting dates.

Even though there was a significant interaction between planting date and cultivar, the differences in basil height at harvest for the two cultivars was due to the variations in plant heights at harvest for the planting dates with each cultivar not for the two cultivars (Table 4).

There was an order of magnitude difference for basil height at harvest between the two cultivars. Thus, cultivar significantly influenced the average basil height ($p \leq 0.05$) in both years (Figure 2). In 2018, ‘Eleonora’ average plant height was 704 cm, while the average plant height for ‘Everleaf’ was 395 cm, or approximately 1.7 times greater average plant height at harvest for ‘Eleonora’ in 2018 (Figure 2). Similarly, in 2019, ‘Eleonora’ average plant height at harvest was 594 cm, and ‘Everleaf’ was 412 cm, resulting in approximately 1.4 times greater harvested plant height for ‘Eleonora’.

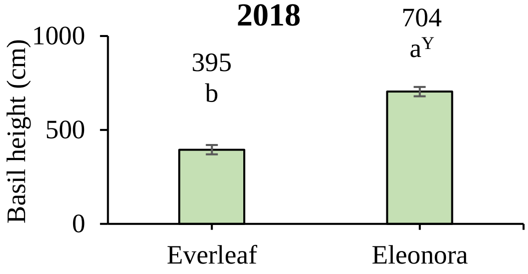

Figure 2. Influence of cultivar on cumulative harvested height for a four plant plot when averaged over row covers, heating cables, and planting dates in 2018.
^{Y} Mean values with different letters for each cultivar indicate significant difference between basil height according to Tukey’s test at α= 0.05. Error bars show standard error.

Basil Weight

Row covers did not influence basil yield (fresh weight) at harvest for either year (Table 3). There was also no significant interaction, with the four-way interaction of row cover by heat by planting date by cultivar as the closest significant interaction in 2018 (p= 0.07). This result also suggests that the transplanting dates should have been earlier, with colder air temperatures in March, so that the effectiveness of the row covers to modify air temperatures around the basil plants in order to evaluate basil yield under more extreme conditions.

There was a significant three-way interaction of heating cables by planting date by cultivar in 2018 (Table 3). This resulted from the significant interaction of planting date by cultivar (p= 0.019) and the significant interaction of heating cables by planting date. Basil transplanted into soil with heating cables had the greatest average fresh weight when harvested (2098 g) with the first planting date, decreasing during each successive planting date (Table 5). Basil transplanted in soil with heating cables had the greatest average fresh weight when harvested (2098 g) with the first planting date, while the lowest average fresh weight when harvested (648 g) was with the third planting date. Results suggest that with heating cables, a longer growing season with the first planting date resulted in the greatest yield. However, without heating cables, yield was more dependent on the fluctuating air temperatures and cloudiness that influenced solarisation than the length of the growing season.

Table 5. Interaction effect of heat and planting date on basil weight (grams) for 2018 growing season within a high tunnel near Absaraka, ND.

Heat	Planting	Plant weight [Z] (g)
H1 [Y]	T1 [X]	1348 ab [W]
H2	T1	2098 a
H1	T2	696 b
H2	T2	1731 a
H1	T3	761 b
H2	T3	648 b

[Z] Cumulative harvested weight over a growing season for a four plant plot.

[Y] Abbreviation H1 = No heat, H2 = Heat

[X] Abbreviation T1 = first transplanting date, T2 = second transplanting date, T3 = third transplanting date.

[W] Mean values with different letters for each year indicate significant difference between heat and planting date according to Tukey’s test at $\alpha = 0.05$.

In 2019, there was no significant interaction with heating cable as a variable (Table 3) .The main effect of heating cables also did not influence basil average fresh weight at harvest, with 1410 g without heating cables and 1511 g with heating cables. Results indicate that when an early spring occurs with warmer air temperatures in April and May, there will be no advantage to using heating cables unless one transplants even earlier.

There was a significant three-way interaction of heating cables by planting date by cultivar in 2018 only for the basil weight at harvest, which resulted from the significant interaction of heating by planting date and the interaction of planting date by cultivar for 2018 (2018 p= 0.036, p = 0.019) (Table 3). In 2018, the interaction occurred because the average basil harvested fresh weight of 'Eleonora' and 'Everleaf' decreased with successive planting dates, but instead of the basil fresh weight being greater with 'Eleonora' with each planting date, the fresh weight for the third planting date was greater with 'Everleaf' (Table 6). The greatest average fresh weight at harvest was with 'Eleonora' when transplanted on the first planting date, while the lowest plant fresh weight at harvest was with 'Eleonora' and 'Everleaf' when transplanted on the third planting dates. In 2019, the interaction occurred again because the basil fresh weight at harvest with 'Eleonora' and 'Everleaf' decreased with successive planting dates, but instead of the basil fresh weight being greater with 'Eleonora' with each planting date, the fresh weight for the third planting date was greater with 'Everleaf' (Table 6).

Table 6. Interaction effect of planting date and cultivar on basil weight (grams) for 2018 and 2019 growing season within a high tunnel near Absaraka, ND.

		Plant weight^{Z} (g)	
Cultivar	Planting	2018	2019
Eleonora	T1 ^{Y}	1991 a ^{X}	2021 a
	T2	1356 bc	1781 ab
	T3	662 c	530 d
Everleaf	T1	1456 b	1828 abc
	T2	1071 bc	1390 bc
	T3	747 bc	1215 c

[Z] Cumulative harvested weight over a growing season for a four plant plot.

[Y] Abbreviation T1 = first transplanting date, T2 = second transplanting date, T3 = third transplanting date.

[X] Mean values with different letters for each year indicate significant difference between planting dates and cultivar according to Tukey's test at α= 0.05.

However, the decrease in average fresh weight at harvest with 'Eleonora' for the third planting was almost twice as much as in 2018. The greatest plant fresh weight at harvest was with ‘Eleonora’ when transplanted on the first or second planting dates or when ‘Everleaf’ was transplanted on the first planting date, while the lowest plant fresh weight at harvest was with ‘Eleonora’ when transplanted on the third planting date. Results suggest that with taller cultivars, such as Eleonora, a longer growing season would be beneficial as the yield decrease from first planting date to the third planting date in 2018 was almost three-fold and almost a four-fold decrease in 2019. In contrast, shorter cultivars, such as Everleaf did not benefit from a longer growing season as the yield decrease from first planting date to the third planting date in 2018 was approximately one-fold in 2018 and around 50% in 2019.

The results found in this study are similar to those found by Hunter et al. (2012) in Logan, UT, in which they tested tomatoes in a high tunnel from 2009 to 2010. They had three different planting dates, and the trial also included the soil heating cables and the low tunnels, which was similar to this trial. The researchers noted that with the addition of heat, early biomass accumulation was significantly greater. The study also showed that early planting dates had a significant positive effect on early yield and that as planting dates were delayed, total yield decreased. A significant interaction between planting date and heat treatment was observed for early marketable tomato yield in 2009. Heat treatment significantly increased yield for tomatoes planted on 17 March; however, it did not affect yield for tomatoes planted on 30 March or 7 April, the later planting dates. However, in 2010, no interaction was observed between the heat treatments and the planting dates. The impact of soil heating on tomato plants was considered somewhat inconclusive by the researchers. As a result of the cooler climate in 2009, the total yield was higher when the heating cables were added.

Bean Yield and Number of Pods

Since the average number of pods harvested directly influences the bean yield, both variables will be discussed together in this section. Row covers did not influence snap bean yield (fresh weight) or the number of pods at harvest for either year (Table 7). There was also no significant four-way interaction of row cover by heating cables by planting date by cultivar and no significant three-way interaction that included row cover. However, there was a significant two-way interaction of row cover by cultivar in 2018 for both yield and number of pods. This result suggests that in 2019 the seeding dates should have been earlier, with colder air temperatures in March, so that the effectiveness of the row covers to modify air temperatures around the emerging bean seedlings in order to evaluate snap bean pod production and yield under more extreme conditions. The bean yield and pod production for 'Amethyst Purple' was the greatest with the clear plastic row cover and decreased as the opaqueness of the row cover material increased (Table 8). The same trend was true for the 'E-Z Pick' yield and pod production with the exception of the yield and pod production under the 71 g white fabric row cover where both yield and pod production increased in comparison with the 28 g white fabric row cover. As previously mentioned, the greatest yield in 2018 was with 'Amethyst Purple' under a clear plastic row cover (1056 g), but this yield was only greater than the yield for 'E-Z Pick' under the 28 g white fabric row cover. The greatest average pod production in 2018 was with 'Amethyst Purple' under a clear plastic row cover (218), but the number of pods was only greater than the pod production for 'E-Z Pick' under the clear plastic or 28 g white fabric row cover. It is unclear what caused this interaction due to the malfunction of the data loggers for the 71 g white fabric row covers in 2018. Clear polyethylene covers typically produce warmer conditions than the more opaque and porous spun bonded covers (Wells and Loy 1985;

Motsenbocker and Bonanno 1989). As a result, clear covers are often more effective than spunbonded materials when warm season crops are grown under cool conditions (Hemphill and Mansour 1986; Motsenbocker and Bonanno 1989). Waterer (1993) also observed that the benefits of using clear covers were most apparent when combined with early planting, as clear plastic promoted crop establishment and growth during adverse outside conditions. The resulting early start allowed a high percentage of crop to start before the regular outside production timeline.

Table 7. ANOVA results with main effect of cover, heat, planting, cultivar, and its interaction effect on bean yield and number of pods for 2018 and 2019 growing season within a high tunnel near Absaraka, ND.

	2018		2019	
Source	Yield [Z]	Number of pods [Y]	Yield	Number of pods
Cover	0.178	0.263	0.665	0.807
Heat	0.732	0.966	0.416	0.534
Planting	0.009**	0.018*	0.027*	0.038*
Cultivar	0.021*	0.003**	0.471	0.47
Cover x Heat	0.907	0.806	0.475	0.637
Cover x Planting	0.074	0.221	0.11	0.127
Heat x Planting	0.243	0.333	0.704	0.779
Cover x Cultivar	0.019*	0.031*	0.717	0.683
Heat x Cultivar	0.68	0.843	0.954	0.775
Planting x Cultivar	0.021*	0.007**	0.287	0.409
C x H x P [X]	0.538	0.706	0.207	0.225
C x H x V	0.546	0.706	0.683	0.829
C x P x V	0.328	0.262	0.89	0.939
H x P x V	0.026*	0.049*	0.694	0.629
C x H x P x V	0.378	0.576	0.538	0.404

'***', '**', '*', indicates significant at p≤ 0.001, p≤ 0.01 and, p≤ 0.05.

[Z] Cumulative weight over a growing season for a four plant plot

[Y] Cumulative number of pods over a growing season for a four plant plot

[X] Abbreviation C= cover, H= Heating cables, P= Planting date V= Cultivar.

Table 8. Influence of row cover and cultivar on snap bean yield and pod production for 2018 in a high tunnel near Absaraka, ND.

Cover	Cultivar	Yield^{Z} (g)	Number of pods^{Y}
C1^{X}	Amethyst Purple	1056 a^{W}	218 a
	E-Z Pick	726 ab	138 b
C2	Amethyst Purple	855 ab	176 ab
	E-Z Pick	580 b	118 b
C3	Amethyst Purple	810 ab	160 ab
	E-Z Pick	931 ab	166 ab

[Z] Cumulative weight over a growing season for a four plant plot

[Y] Cumulative number of pods over a growing season for a four plant plot

[X] Abbreviation C1 = clear plastic row cover, C2 = 28 g white fabric row cover, C3 = 71 g white fabric row cover.

[W] Mean values with different letters for each year indicate significant difference of the interaction between row cover and cultivar according to Tukey's test at $\alpha = 0.05$.

There was a significant three-way interaction of heating cables by planting date by cultivar for yield and pod production in 2018 (Table 7). This was attributed to the significant planting date by cultivar interaction. ‘Amethyst Purple’ planted on the first and second planting date had similar yields and significantly greater yields than the third planting (94 and 83%, respectively), while the yields for ‘E-Z Pick for all three planting dates were similar (Figure 5). For pod production, the greatest number of pods produced for ‘Amethyst Purple’ occurred with the second planting date, which was similar to the pod production for the first planting date and significantly greater than the pod production for the third planting date (Table 9). Pod production for ‘E-Z Pick’ was also greatest with the second planting, but was not different from the pod production from the first or third planting date. Results suggest that ‘Amethyst Purple’ has a greater yield potential when provided with adequate soil and air temperatures for growth, which occurred earlier during the growing season compared to later in the growing season. ‘E-Z Pick’, on the other hand, had a lower yield potential, but was more adapted to heat stresses that would occur later in the growing season.

Table 9. Influence of planting date and cultivar on bean yield and pod numbers for 2018 in a high tunnel near Absaraka, ND.

Planting date	Cultivar	Yield[Z] (g)	No. of pods[Y]
T1 [X]	Amethyst Purple	1105 a [W]	201 ab
	E-Z Pick	785 abc	128 c
T2	Amethyst Purple	1046 ab	230 a
	E-Z Pick	764 abc	150 bc
T3	Amethyst Purple	570 c	122 c
	E-Z Pick	688 bc	142 bc

[Z] Cumulative weight over a growing season for a four plant plot

[Y] Cumulative number of pods over a growing season for a four plant plot

[X] Abbreviation T1 = first transplanting date, T2 = second transplanting date, T3 = third transplanting date.

[W] Mean values with different letters indicate significant difference between planting dates and cultivar according to Tukey's test at α= 0.05.

The main effect of planting date was significant for average bean yield in 2019. The snap beans planted on the first planting date had the greatest yield (945 g), which was significantly greater ($p \leq 0.05$) than the yield (629 g) from the third planting date (Figure 3). Snap beans planted on the second planting date yielded 905 g, which was also significantly greater than the yield from the third planting date in 2018.

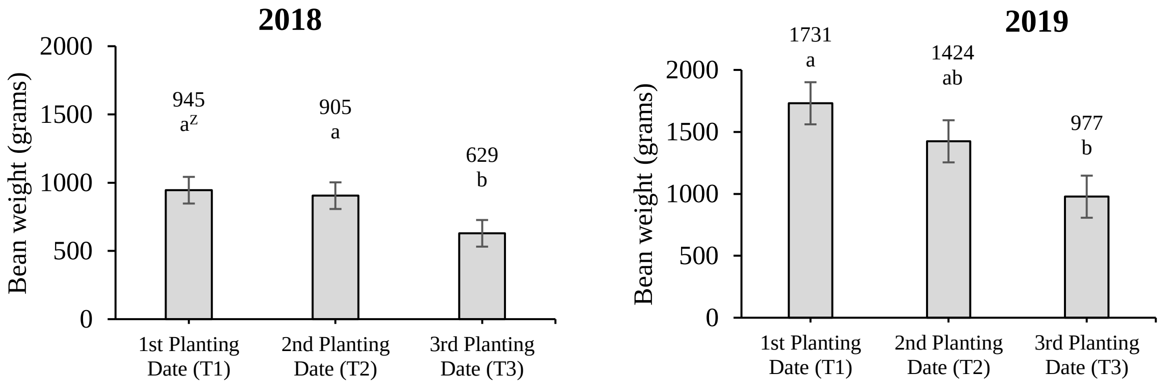

Figure 3. Main effect of planting date on cumulative bean yield of a four-plant plot for 2018 and 2019 growing season under Absaraka, ND high tunnel.

[Z] Mean values with different letters for each year indicate significant difference between planting date according to Tukey's test at α= 0.05. Error bars show standard error.

The interaction of planting date by cultivar in 2018 was previous explained (Table 7). There was no interaction of planting date by cultivar in 2019. However, the main effect of cultivar was also insignificant in 2019. Results suggest that when an early spring occurs and soil/air temperature modification is not beneficial, both snap bean cultivars will have similar yields.

The main effect of planting had significant effect on the average bean pod numbers in both 2018 and 2019. In 2018, the beans planted on the 2nd planting date produced 190 beans on an average which was significantly different to the 132 beans, planted on the 3rd planting date (Figure 4). Similarly, the first planting date produced 165 beans on an average.

In 2019, the first planting date had 336 beans on an average which was significantly different to the 3rd planting date producing 199 beans, approximately double number of pods.

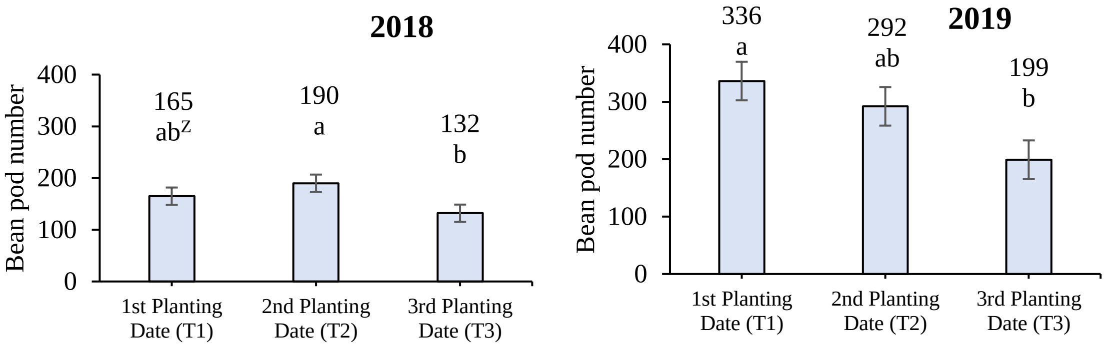

Figure 4. Main effect of planting date on cumulative bean pod number for a four-plant plot in 2018 and 2019 growing seasons under Absaraka, ND high tunnel.
[Z] Mean values with different letters for each year indicate significant difference between planting date according to Tukey's test at α= 0.05.

SUMMARY

Comparing the two years, 2019 was warmer than 2018 (Table A1). For example, when comparing the daily maximum and minimum air temperature, April 2018 had an average maximum and minimum of 5.5°C and -5.6°C, respectively, while April 2019 had an average maximum and minimum of 9.8°C and 0.33°C, respectively. In 2019, we had to re-seed the beans again as some of the bean seedlings failed to germinate while others planted during the first planting date had the plastic cover burned the bean seedlings due to excessive heat inside the cover when the temperature exceeded the published optimal temperature for the beans in the second week of May. Low tunnel temperatures should be monitored regularly because they can easily become excessive from an optimal range (Kinet and Peet, 1997). In contrast to clear plastic, both of the other fabrics are breathable and did not harm the plants. More research is needed to compare the temperature modification of a row cover to a low tunnel covering multiple rows with and without heating cables. Also the cost of the row covers and the tunnels should be evaluated to know if it is affordable in the long run for the growers. Purchasing row covers, however, will require extra capital, as well as more labour to install and remove them during periods of high daytime temperatures and when plants are flowering.

Supplemental heating was observed to increase the soil temperature relative to the control. The study revealed that soil heating used resulted in increased plant height for basil. There was a significant effect of row covers on bean yield. The clear plastic produced a greater number of pods and bean weight in bean crops compared to the other fabrics. The higher yield was observed in the bean and basil crops planted on the first planting date. The results indicate that supplemental soil heating and frost protection allow for productive yields from early planting dates. Local farmers taking advantage of these season extending techniques may be able to harvest a more diverse array of produce to regional markets earlier in the season.

CONCLUSION

Supplemental heating was observed to increase the soil temperature relative to the control when the temperature was cooler in the early spring. The study revealed that soil heating used resulted in increased cumulative plant height and weight for basil. There were a significant effect of row covers on bean cultivars yield. The cumulative bean yield and pod production for ‘Amethyst Purple’ was the greatest at harvest with the clear plastic row cover. The higher cumulative yield was observed in the bean and basil crops planted on the first planting date. The results indicate that supplemental soil heating and frost protection allow higher yield benefits from early planting dates.

FUTURE RESEARCH

We can conduct a comprehensive investigation of the placement and the depth of the heating cables to determine the optimum depth for growth and assess the effects of supplemental soil heating specially in March to know the effectiveness of the heating cables. Studies to compare row covers placed in floating positions with row covers suspended over plants using wire hoops and suspended over the entire greenhouse floor using greenhouse length wires may provide valuable information to optimize growth and cold protection. Moreover, row covers provided extra frost protection in addition to a high tunnel. In short, further research should be devoted to determining the most appropriate planting dates based on varieties to reach maximum yield and season extension. The management of temperature would be simplified if the entire high tunnel was dedicated to a single crop.

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APPENDIX A. SUPPLEMENTAL MATERIAL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1.5	3	4.5	6	7.5	9	10.5	12	13.5	16.5	18	19.5	21	22.5	24	25.5	27	28.5
T1	T2	T3	T1	T3	T3	T2	T1	T2	T2	T1	T2	T3	T1	T2	T1	T3	T3
H1	H2	H2	H1	H2	H1	H2	H2	H1	H1	H2	H2	H1	H1	H1	H2	H2	H1
C2	C3	C3	C3	C2	C1	C2	C2	C2	C3	C1	C1	C3	C1	C1	C3	C1	C2
Bean 2	Basil 2	Bean 1	Basil 2	Bean 1	Basil 2	Basil 1	Basil 1	Basil 1	Bean 1	Bean 1	Bean 2	Basil 1	Bean 1	Bean 1	Bean 2	Basil 1	Basil 1
T1	T2	T3	T1	T3	T3	T2	T1	T2	T2	T1	T2	T3	T1	T2	T1	T3	T3
H1	H2	H2	H1	H2	H1	H2	H2	H1	H1	H2	H2	H1	H1	H1	H2	H2	H1
C2	C3	C3	C3	C2	C1	C2	C2	C2	C3	C1	C1	C3	C1	C1	C3	C1	C2
Bean 1	Basil 1	Bean 2	Bean 1	Basil 1	Bean 2	Basil 2	Basil 2	Bean 2	Basil 1	Bean 2	Bean 1	Bean 2	Bean 2	Basil 2	Basil2	Basil 2	Bean 2
T1	T2	T3	T1	T3	T3	T2	T1	T2	T2	T1	T2	T3	T1	T2	T1	T3	T3
H1	H2	H2	H1	H2	H1	H2	H2	H1	H1	H2	H2	H1	H1	H1	H2	H2	H1
C2	C3	C3	C3	C2	C1	C2	C2	C2	C3	C1	C1	C3	C1	C1	C3	C1	C2
Basil 2	Bean 1	Basil 1	Bean 2	Basil 2	Bean 1	Bean 2	Bean 2	Basil 2	Basil 2	Basil 2	Basil 1	Bean 1	Basil 1	Basil 1	Basil 1	Bean 2	Basil 2
T1	T2	T3	T1	T3	T3	T2	T1	T2	T2	T1	T2	T3	T1	T2	T1	T3	T3
H1	H2	H2	H1	H2	H1	H2	H2	H1	H1	H2	H2	H1	H1	H1	H2	H2	H1
C2	C3	C3	C3	C2	C1	C2	C2	C2	C3	C1	C1	C3	C1	C1	C3	C1	C2
Basil 1	Bean 2	Basil 2	Basil 1	Bean 2	Basil 1	Bean 1	Bean 1	Bean 1	Bean 2	Basil 1	Basil 2	Basil 2	Basil 2	Bean 2	Bean 1	Bean 1	Bean 1
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218
T1	T2	T1	T3	T1	T3	T1	T2	T2	T3	T1	T3	T2	T1	T2	T3	T2	T3
H2	H2	H1	H1	H1	H2	H2	H2	H1	H2	H1	H1	H2	H2	H1	H2	H1	H1
C1	C3	C1	C3	C2	C2	C2	C1	C2	C3	C3	C2	C2	C3	C3	C1	C1	C1
Basil 2	Basil 2	Bean 1	Basil 1	Bean 2	Bean 1	Basil 1	Bean 2	Basil 1	Bean 1	Basil 2	Basil 1	Basil 1	Bean 2	Bean 1	Basil 1	Bean 1	Basil 2
T1	T2	T1	T3	T1	T3	T1	T2	T2	T3	T1	T3	T2	T1	T2	T3	T2	T3
H2	H2	H1	H1	H1	H2	H2	H2	H1	H2	H1	H1	H2	H2	H1	H2	H1	H1
C1	C3	C1	C3	C2	C2	C2	C1	C2	C3	C3	C2	C2	C3	C3	C1	C1	C1
Bean 2	Basil 1	Bean 2	Bean 2	Bean 1	Basil 1	Basil 2	Bean 1	Bean 2	Bean 2	Bean 1	Bean 2	Basil 2	Basil2	Basil 1	Basil 2	Basil 2	Bean 2
T1	T2	T1	T3	T1	T3	T1	T2	T2	T3	T1	T3	T2	T1	T2	T3	T2	T3
H2	H2	H1	H1	H1	H2	H2	H2	H1	H2	H1	H1	H2	H2	H1	H2	H1	H1
C1	C3	C1	C3	C2	C2	C2	C1	C2	C3	C3	C2	C2	C3	C3	C1	C1	C1
Basil 1	Bean 1	Basil 1	Bean 1	Basil 2	Basil 2	Bean 2	Basil 1	Basil 2	Basil 1	Bean 2	Basil 2	Bean 2	Basil 1	Basil 2	Bean 2	Basil 1	Bean 1
T1	T2	T1	T3	T1	T3	T1	T2	T2	T3	T1	T3	T2	T1	T2	T3	T2	T3
H2	H2	H1	H1	H1	H2	H2	H2	H1	H2	H1	H1	H2	H2	H1	H2	H1	H1
C1	C3	C1	C3	C2	C2	C2	C1	C2	C3	C3	C2	C2	C3	C3	C1	C1	C1
Bean 1	Bean 2	Basil 2	Basil 2	Basil 1	Bean 2	Bean 1	Basil 2	Bean 1	Basil 2	Basil 1	Bean 1	Bean 1	Bean 1	Bean 2	Bean 1	Bean 2	Basil 1
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118

Figure A1. Experimental plot design 2018.

Table A1. The average monthly maximum, minimum and average air temperature trend outside the high tunnel from April to October in 2018 and 2019.

Month	Max Temp °C	Min Temp °C	Avg Temp °C	Max Temp °C	Min Temp °C	Avg Temp °C
		2018			2019	
April	5.5	-5.6	-0.04	9.8	0.33	5.0
May	25.0	8.7	16.9	17.3	4.0	10.7
June	26.8	14.2	20.5	26.0	12.3	19.2
July	26.9	13.6	20.3	28.1	15.6	21.9
August	26.7	12.0	19.4	24.3	12.5	18.4
September	20.9	7.4	14.1	20.7	10.3	15.5
October	9.0	-1.4	3.8	8.6	0.7	4.6

Weather data obtained from NDAWN Weather station near Absaraka, ND.

Table A2. Analysis of Variance for Average basil fresh weight produced in the high tunnel in Absaraka, ND in 2018.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	45412	2	0.3889	NS	
Heat	1242871	1	10.6428	0.0046	**
Planting	1383811	2	11.8497	0.0006	***
Variety	1083761	1	9.2803	0.0069	**
Cover x Heat	165003	2	1.4129	NS	
Cover x Planting	72101	4	0.6174	NS	
Heat x Planting	476223	2	4.0779	0.0358	*
Cover x Variety	388144	2	3.3237	NS	.
Heat x Variety	35756	1	0.3062	NS	
Planting x Variety	583028	2	4.9925	0.0188	*
Cover x Heat x Planting	90241	4	0.7727	NS	
Cover x Heat x Variety	204431	2	1.7506	NS	
Cover x Planting x Variety	287194	4	2.4593	NS	.
Heat x Planting x Variety	510043	2	4.3675	0.0284	*
Cover x Heat x Planting x Variety	305540	4	2.6164	NS	

***, **, * Significant at $p \leq 0.001, 0.01, 0.05$. NS = non-significant

Table A3. Analysis of Variance for Average basil height produced in the high tunnel in Absaraka, ND 2018.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	5586	2	0.6627	NS	
Heat	42615	1	5.0561	0.0373	*
Planting	46403	2	5.5055	0.0136	*
Variety	1720992	1	204.1850	0.0000	***
Cover x Heat	10231	2	1.2138	NS	
Cover x Planting	4485	4	0.5321	NS	
Heat x Planting	9949	2	1.1804	NS	
Cover x Variety	8363	2	0.9922	NS	
Heat x Variety	8363	1	0.9922	NS	
Planting x Variety	80924	2	9.6011	0.0015	**
Cover x Heat x Planting	2285	4	0.2711	NS	
Cover x Heat x Variety	7800	2	0.9255	NS	
Cover x Planting x Variety	9818	4	1.1649	NS	
Heat x Planting x Variety	34949	2	4.1465	0.0330	*
Cover x Heat x Planting x Variety	11709	4	1.3892	NS	

***, **, * Significant at $p \leq 0.001$, 0.01, 0.05. NS = non-significant

Table A4. Analysis of Variance for Average basil fresh weight produced in the high tunnel in Absaraka, ND in 2019.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	8962	2	0.0808	NS	
Heat	55450	1	0.5000	NS	
Planting	1688008	2	15.2223	0.0002	***
Variety	19767	1	0.1783	NS	
Cover x Heat	32905	2	0.2967	NS	
Cover x Planting	23081	4	0.2081	NS	
Heat x Planting	6719	2	0.0606	NS	
Cover x Variety	157804	2	1.4231	NS	
Heat x Variety	5530	1	0.0499	NS	
Planting x Variety	3278896	2	29.5688	0.0000	***
Cover x Heat x Planting	17444	4	0.1573	NS	
Cover x Heat x Variety	95158	2	0.8581	NS	
Cover x Planting x Variety	188027	4	1.6956	NS	
Heat x Planting x Variety	14107	2	0.1272	NS	
Cover x Heat x Planting x Variety	40243	4	0.3629	NS	

***, **, * Significant at $p \leq 0.001$, 0.01, 0.05. NS = non-significant

Table A5. Analysis of Variance for Average basil height produced in the high tunnel in Absaraka, ND 2019.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	8472	2	2.6419	NS	
Heat	8961	1	2.7943	NS	
Planting	583364	2	181.9032	0.0000	***
Variety	596596	1	186.0294	0.0000	***
Cover x Heat	1156	2	0.3604	NS	
Cover x Planting	967	4	0.3016	NS	
Heat x Planting	2529	2	0.7885	NS	
Cover x Variety	1274	2	0.3971	NS	
Heat x Variety	1644	1	0.5125	NS	
Planting x Variety	732914	2	228.5356	0.0000	***
Cover x Heat x Planting	1015	4	0.3164	NS	
Cover x Heat x Variety	2770	2	0.8639	NS	
Cover x Planting x Variety	3323	4	1.0361	NS	
Heat x Planting x Variety	13785	2	4.2985	0.0298	*
Cover x Heat x Planting x Variety	3452	4	1.0764	NS	

***, **, * Significant at $p \leq 0.001, 0.01, 0.05$. NS = non-significant

Table A6. Analysis of Variance for Average bean weight produced in the high tunnel in Absaraka, ND 2018.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	138992	2	1.9165	NS	
Heat	8806	1	0.1214	NS	
Planting	458658	2	6.3243	0.0088	**
Variety	467384	1	6.4446	0.0206	*
Cover x Heat	7108	2	0.0980	NS	
Cover x Planting	187387	4	2.5838	NS	.
Heat x Planting	111511	2	1.5376	NS	
Cover x Variety	363274	2	5.0090	0.0186	*
Heat x Variety	12720	1	0.1754	NS	
Planting x Variety	351592	2	4.8480	0.0207	*
Cover x Heat x Planting	58445	4	0.8059	NS	
Cover x Heat x Variety	45365	2	0.6255	NS	
Cover x Planting x Variety	90160	4	1.2432	NS	
Heat x Planting x Variety	326052	2	4.4958	0.0261	*
Cover x Heat x Planting x Variety	81193	4	1.1195	NS	

***, **, * Significant at $p \leq 0.001, 0.01, 0.05$. NS = non-significant

Table A7. Analysis of Variance for Average pod number produced in the high tunnel in Absaraka, ND 2018.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	4108	2	1.4479	NS	
Heat	5	1	0.0018	NS	
Planting	14463	2	5.0974	0.0184	*
Variety	34892	1	12.2978	0.0025	**
Cover x Heat	621	2	0.2190	NS	
Cover x Planting	4533	4	1.5976	NS	
Heat x Planting	3332	2	1.1742	NS	
Cover x Variety	12015	2	4.2348	0.0311	*
Heat x Variety	115	1	0.0405	NS	
Planting x Variety	18681	2	6.5840	0.0071	**
Cover x Heat x Planting	1541	4	0.5432	NS	
Cover x Heat x Variety	1007	2	0.3548	NS	
Cover x Planting x Variety	4082	4	1.4388	NS	
Heat x Planting x Variety	10148	2	3.5766	0.0492	*
Cover x Heat x Planting x Variety	2105	4	0.7418	NS	

***, **, * Significant at $p \leq 0.001, 0.01, 0.05$. NS = non-significant

Table A8. Analysis of Variance for Average bean weight produced in the high tunnel in Absaraka, ND 2019.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	48397	1	0.1966	NS	
NSHeat	174786	1	0.7102	NS	
Planting	1224032	2	4.9732	0.0267	*
Variety	136108	1	0.5530	NS	
Cover x Heat	133665	1	0.5431	NS	
Cover x Planting	657515	2	2.6715	NS	
Heat x Planting	89095	2	0.3620	NS	
Cover x Variety	34027	1	0.1382	NS	
Heat x Variety	850	1	0.0035	NS	
Planting x Variety	341328	2	1.3868	NS	
Cover x Heat x Planting	443965	2	1.8038	NS	
Cover x Heat x Variety	43200	1	0.1755	NS	
Cover x Planting x Variety	28995	2	0.1178	NS	
Heat x Planting x Variety	92680	2	0.3766	NS	
Cover x Heat x Planting x Variety	160832	2	0.6535	NS	

***, **, * Significant at $p \leq 0.001, 0.01, 0.05$. NS = non-significant

Table A9. Analysis of Variance for Average pod number produced in the high tunnel in Absaraka, ND 2019.

Source	Mean Sq	NumDF	F-value	Pr(>F)	
Cover	579	1	0.0626	NS	
Heat	3800	1	0.4109	NS	
Planting	40011	2	4.3258	0.0385	*
Variety	5146	1	0.5564	NS	
Cover x Heat	2169	1	0.2345	NS	
Cover x Planting	22758	2	2.4605	NS	
Heat x Planting	2360	2	0.2551	NS	
Cover x Variety	1622	1	0.1753	NS	
Heat x Variety	792	1	0.0856	NS	
Planting x Variety	8910	2	0.9633	NS	
Cover x Heat x Planting	15668	2	1.6940	NS	
Cover x Heat x Variety	450	1	0.0487	NS	
Cover x Planting x Variety	584	2	0.0631	NS	
Heat x Planting x Variety	4465	2	0.4828	NS	
Cover x Heat x Planting x Variety	9044	2	0.9778	NS	

***, **, * Significant at $p \leq 0.001, 0.01, 0.05$. NS = non-significant

APPENDIX B. ADDITIONAL FIGURES

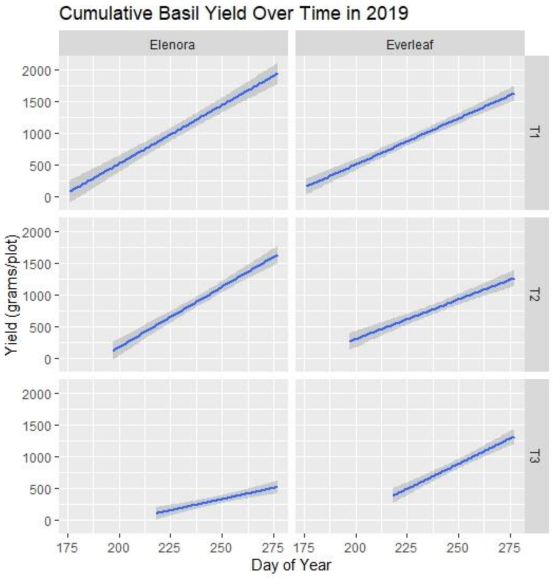

Figure B1. Cumulative harvested bean weight of a four-plant plot over time in response to cultivar and planting date for 2018 growing season in a high tunnel near Absaraka, ND. Results are averaged over levels of cover and heat.
Data are regression lines bounded by 95% confidence intervals.

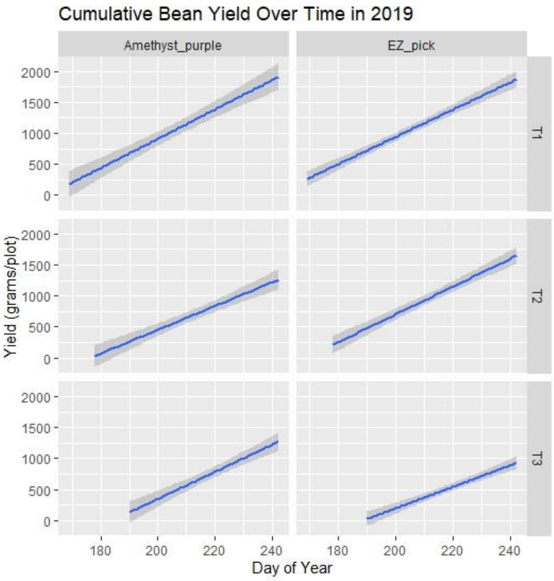

Figure B2. Cumulative harvested bean weight of a four-plant plot over time in response to cultivar and planting date for 2019 growing season in a high tunnel near Absaraka, ND. Results are averaged over levels of cover and heat.
Data are regression lines bounded by 95% confidence intervals.

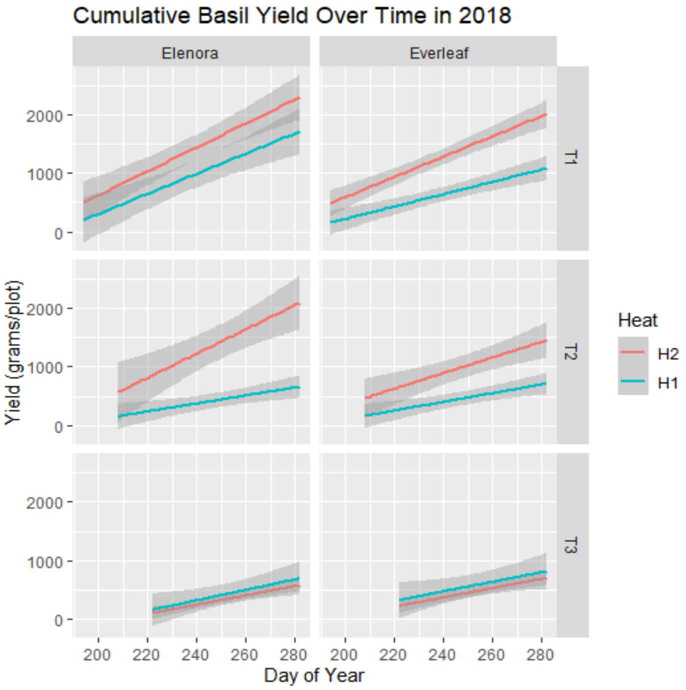

Figure B3. Cumulative harvested basil weight of a four-plant plot over time in response to cultivar, planting date and heat for 2018 growing season in a high tunnel near Absaraka, ND. Results are averaged over levels of cover.

Data are regression lines bounded by 95% confidence intervals.

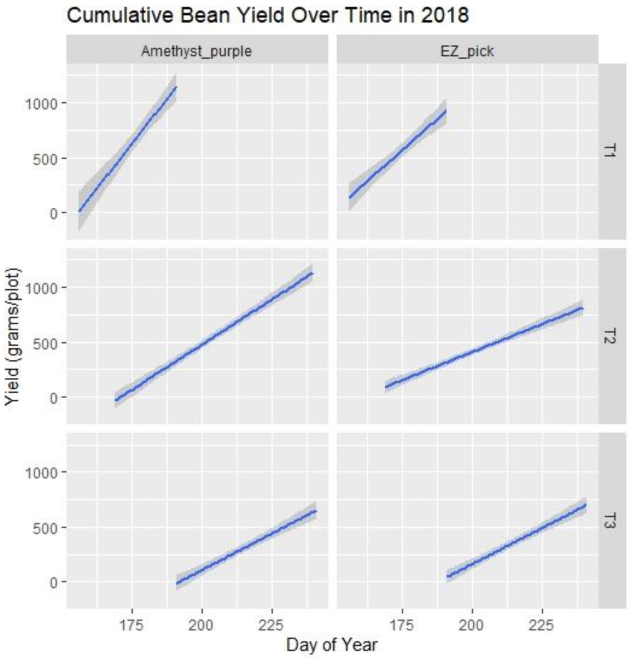

Figure B4. Cumulative harvested basil weight of a four-plant plot over time in response to cultivar and planting date and heat for 2019 growing season in a high tunnel near Absaraka, ND. Results are averaged over levels of cover and heat.

Data are regression lines bounded by 95% confidence intervals.

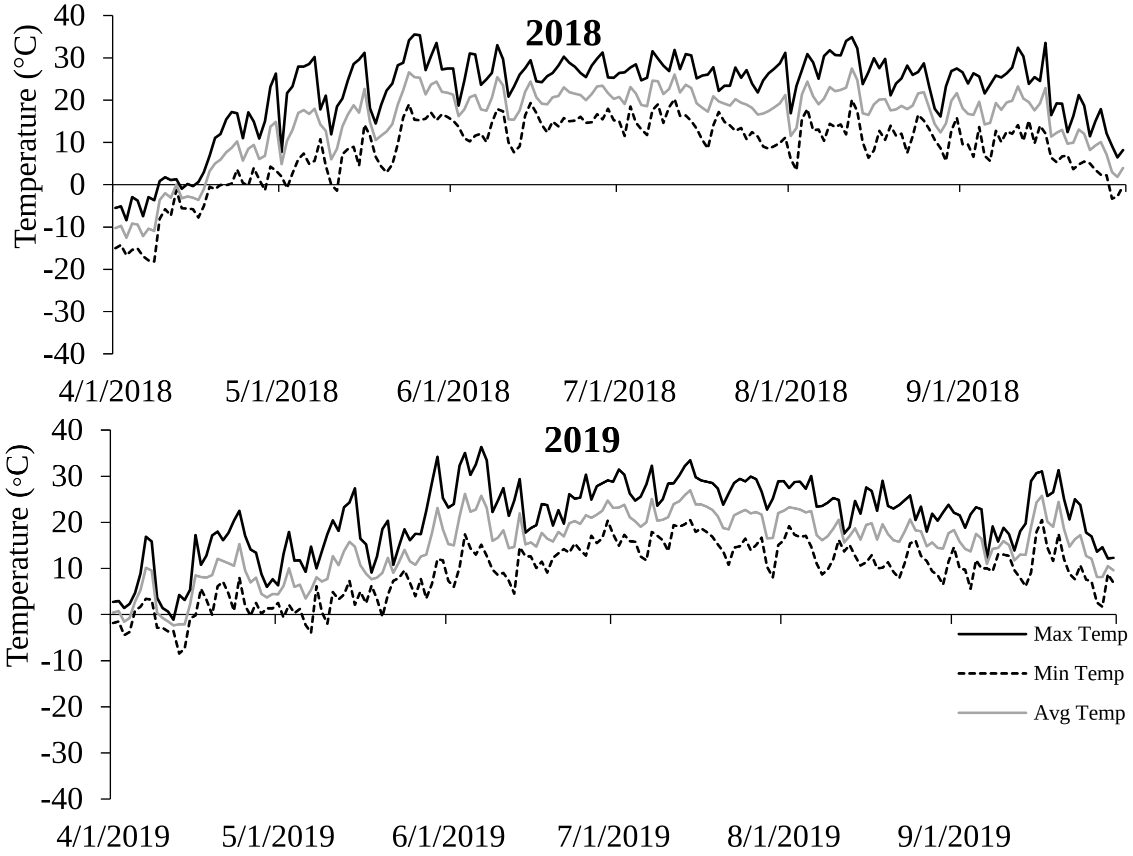

Figure B5. Daily Maximum, minimum, and average air temperature outside the high tunnel from April to September in 2018 and 2019.

Weather data obtained from NDAWN Weather station near Absaraka,ND.

Figure B6. Drip tape installation after rototilling in high tunnel near Absaraka, ND.

Figure B7. Using row covers to protect the crops from frost in high tunnel near Absaraka, ND.