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EFFECT OF PINCHING AND SPACING ON THE GROWTH AND DEVELOPMENT OF SUNFLOWERS (HELIANTHUS ANNUUS) IN EAST TEXAS

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EFFECT OF PINCHING AND SPACING ON THE GROWTH AND DEVELOPMENT OF SUNFLOWERS (*HELIANTHUS ANNUUS)* IN EAST TEXAS

By

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Abstract

Helianthus annuus cultivars were grown in East Texas to evaluate the effect of pinching and spacing on their growth and development. The first experiment was conducted twice (Trial 1A, 28 April 2017 and Trial 1B, 3 August 2017) to evaluate the effect of pinching at nodes 1, 2, 3, and 4 on sunflower cultivars ‘Superior Gold’, ‘Pro Cut Gold’, ‘Sun Bright Supreme’, ‘Vincent’s Choice’, and ‘Sunrich Lemon’. For trial 1A, all the non-pinched treatments for the five cultivars produced marketable stem lengths, stem diameters, flower diameters, and disk diameters. For the cultivar ‘Superior Gold’ all the treatments produced marketable stems. Only the pinching treatment at node 4 failed to produce marketable stems for the cultivars ‘Sun Bright Supreme’, ‘Vincent’s Choice’, and ‘Pro Cut Gold’. Only the non-pinched and pinching treatment at node 1 produced marketable stems for ‘Sunrich Lemon’. For trial 1B, all the non-pinched treatments for the five cultivars produced marketable stem lengths, stem diameters, flower diameters, and disk diameters. All the treatments of ‘Superior Gold’ produced marketable stems. The pinching treatment at nodes 2 and 3 produced marketable stems for ‘Vincent’s Choice’ sunflowers. Only the pinching treatment at node 1 failed to produce a marketable stem for ‘Sun Bright Supreme’ sunflowers whereas ‘Pro Cut Gold’ did not produce marketable stems when pinched at nodes 1 and 3. Only the pinching treatment at node 3 failed to produce marketable stems for the cultivar ‘Sunrich Lemon’. Trial 1A was successful in producing marketable stems for all the above mentioned cultivars except the

cultivar ‘Sunrich Lemon’ whereas trial 1B failed to produce marketable stems for multiple cultivars. These results indicate that the success of pinching depends on the season of growing sunflowers. In East Texas pinching was successful when it was done in the spring (late April) whereas the success of pinching decreased when it was performed in late summer (August).

The second experiment evaluated the effect of spacing on the sunflower cultivars ‘Superior Gold’, ‘Pro Cut Gold’, and ‘Sunrich Lemon’. The spacing treatments were 30 × 30 cm, 23 × 23 cm, 15 × 15 cm, and 8 × 15 cm. All three cultivars successfully produced marketable stem lengths and flower diameters. The cultivar ‘Superior Gold’ produced marketable sunflowers for all the spacing treatments whereas ‘Pro Cut Gold’ produced marketable sunflowers for the 15 × 15 and 8 × 15 cm spacing treatments. The cultivar ‘Sunrich Lemon’ failed to produce marketable stem diameter and disk diameter for all the four spacing treatments. These results indicate that spacing treatments affect sunflower development. High plant density was successful for ‘Superior Gold’ and ‘Pro Cut Gold’, but high density planting was not successful for the cultivar ‘Sunrich Lemon’ during late summer.

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INTRODUCTION

The specialty cut flower industry has been growing rapidly in the past few years, producing new and rediscovered species. Cut flowers are flower buds with stems and leaves. The purpose of cut flowers is usually to use them as indoor decoration. The value of wholesale standard cut flowers including chrysanthemum, roses, carnations etc. decreased moderately from 1987 to 1990. There was a continuous decrease in domestic cut flower production within the United States of America in the 1970's and 1980's due to increased imports from other countries (Bonarriva, 2003). Industry reports suggested that the United States of America has a diverse market of cut flowers with imported cut flowers from around the world.

Pinching is a technique in which the plant is pruned to encourage lateral branching. In pinching the apical meristem is removed, forcing the plant to grow two or more new stems from the nodes below the pinch. Experiments conducted by Dr. Wien showed that pinching sunflowers resulted in more harvestable flowers, approximately four times more than those of the non-pinched sunflowers (Wien, 2012a). Pinching delays flowering and reduces flower size. Over the last few years a lot of work has been done on pinching of sunflowers, yet researchers are not sure at which time of the growing season pinching should be done to obtain the maximum yield of sunflowers.

In addition spacing is a very important technique used for growing sunflower crops for both agronomic and horticultural purposes. Oil seed sunflower crops are planted densely for the purpose of obtaining more oil as compare to the non-oil seed cultivars. For cut flower production increased spacing between the plants is desired since flower size and stem growth are more important rather than the seed size.

To address these issues, this research evaluated the effect of pinching and spacing on sunflowers by implementing two techniques in two different experiments. For experiment 1, plants were spaced at a distance of 23 × 23 cm and pinched at nodes 1, 2, 3, and 4. For experiment 2 seeds were sown at spacings of 30 × 30 cm, 23 × 23 cm, 15 × 15 cm, and 8 × 15 cm.

OBJECTIVES

There are two main objectives of this research:

1. Determine how pinching sunflowers at different nodes with the same spacing affects the stem length, stem diameter, flower size, flower disk size, time to harvest, and number of stems.
2. Determine how sunflower spacing affects the development of stem length, stem diameter, flower size, flower disk size, and time to harvest.

LITERATURE REVIEW

History of sunflowers

Sunflowers belong to the genus *Helianthus*, a member of the Asteraceae family often referred to as Compositae in earlier texts (Heiser, 1978). There are 49 species of *Helianthus* native to North America (Seilera, 1992). Sunflower (*Helianthus annuus* L.*)* is widely cultivated for its oil throughout the world and classified as a moderately salt tolerant crop (Ashraf and Tufail, 1995). Phenotypic and genotypic studies reveal that sunflowers have the potential to be grown in places where other crops have failed. It is grown on more than 22 million hectares with production of 120 million tons of oil (Shirshikar, 2005; Skoric et al., 2007). Sunflowers originated from North America, where they were grown by native people for medicinal and food purposes (Putt, 1978). Heliotropism is from the Greek word *helios*, meaning sun, and *trope*, meaning turn (Hart, 1990). This type of plant movement can be described as the plant's response to turgor changes causing movement towards sunlight (Hart, 1990). Schaffer (1898) reported that sunflower buds and leaves show movement in response to sunlight. In the United States, cut sunflowers are mainly grown in New Jersey, Pennsylvania and Califor

The oil extracted from the sunflower seeds is also known as premium oil because it can withstand high cooking temperatures, has a light color, and low levels of fats (Myers and Minor, 1993). *Helianthus annuus L.* has a high protein and oil content, ranging between 15-20% and 25-48%, respectively (Weiss, 1983). In the early 1990's sunflowers regained popularity as a specialty cut flower, increasing business and the economic importance of the crop (Celikel and Reid, 2002; Devecchi, 2005; Yanez et al., 2005). Remarkable change has been observed in the rank of sunflowers from 35th to 18th at the Dutch flower auction from 1995 to 2000 (Devecchi, 2005). The development of new cultivars and colorful flowers are the reasons for the revival of sunflowers (Armitage and Laushman, 2003; Fanelli et al., 2001). Currently scientists are breeding sunflowers for many characteristics, like flower size, flower color, plant height, disk size, branching, and non-branching habit. The availability of sunflowers throughout the year is another reason for their demand (Armitage and Laushman, 2003). Sunflowers are easily adapted to a wide range of soil and climatic conditions. Sunflowers can be grown from Argentina to Canada including semi-arid regions.

Sunflowers grow well in clay soils and full sun light (Armitage and Laushman, 2003; Dole and Wilkins, 2005; Stevens et al., 1993; Schoellhorn et al., 2003). A pH range of 5.7 to 8.0 is ideal for sunflower production (Putnam et al., 1990). Lack of sufficient water during the vegetative and flowering stages of growth delays growth and flowering.

There are certain issues that producers have to deal with while growing sunflowers. Low yield is one of the main issues. Low yield of sunflowers is due to several factors. These factors include poor agronomic cultivation methods, adverse climate, and damage caused by various insects. There are many diseases which can impact a crop of sunflowers even under optimal growing conditions (Mirza and Beg, 1983).

Development of flowers in *Helianthus annuus*

After the development of bracts around the margins of the shoot apex the reproductive stage of the *Helianthus annuus* begins (Schneiter and Miller, 1981; Schuster, 1985). Temperature and photoperiod affect flower development from the time of seedling emergence (Schuster, 1985). Many authors have suggested that sunflowers are a day neutral species, but there are many cultivars that are not day neutral and are either long-day or short-day cultivars (Schuster, 1985). Some cultivars have a reduced vegetative period depending on certain factors. Warmer temperature may accelerate flowering (Schuster, 1985). Schneiter and Miller (1981) described the five reproductive stages of sunflower. Stage R1 is evident due to the formation of a flower bud encircled by immature bracts. These bracts give a star like appearance when observed from the top. In stage R2 elongation of internodes occurs. In stage R3 elongation of internodes continues, thus lifting the flower head above the surrounded leaves. Opening of bracts that are covering the inflorescence occurs in the R4 stage. Initiation of flowering starts in the R5 stage.

Types of Sunflowers

Branching, single stem, and spray are flowering types of the sunflower cultivars. There are two basic categories for the production of sunflowers as cut flowers, single stem type and branching type. Single stem cultivars, also known as non-branching cultivars, are mostly pollen-less hybrids. Pro Cut and Sunrich series are examples of single stem cultivars. The single stem cultivars ‘Pro Cut Gold’ and ‘Sunrich Lemon’ have one single thick, strong stem with only one terminal head. Single stem cultivars produce only one large flower per plant.

Branching cultivars, having multiple axillary shoots and buds produce numerous blooms (Armitage and Laushman, 2003). ‘Floristan’, ‘Helios Flame’, and ‘Moon Walker’ are examples of branching cultivars. The stems of branching cultivars are not as long and thick as the non-branching cultivars.

Spray cultivars are those cultivars which produce a bunch of flower buds, but these flowers don’t have the optimum head size as required by the market. ‘Moon Bright’ is an example of a spray cultivar. Spray cultivars are much shorter as compared to the single stem and branching cultivars.

Pinching

Pinching is a technique where growers remove the apical meristem at an early stage to encourage the development of lateral shoots, resulting in more flowers. Pinching at the suitable nodal point is an important factor for increasing the number of flowers. There are different hypothesis regarding the control of branching. The classical hypothesis states that auxin acts to regulate shoot branching in conjunction with secondary messengers, such as cytokinin (Bangerth, 1994; Li et al., 1995).

Pinching should be done at the right stage, with careful consideration of whether it will be beneficial or injurious to the plants (Smakel, 2006). Pinching done vigorously at the seedling stage enhances both vegetative growth as well as bud development (Mathew and Karikari, 1995). Wien (2015) stated that removal of the apical meristem induces production of lower branches. Pinching done at the 4 node stage resulted in an increase in the number of stems per plant (Wien, 2006).

The Specialty Cut Flower Grower Association reported that several cultivars of the single stem sunflowers ‘Pro Cut Gold’ and ‘Sunrich Lemon’ were too large to be used by florists, while other cultivars are freely branched and produce small stems and flowers (Dole, 2003). Emino and Hamilton (2004) tried to optimize the size of stems and flowers by the removal of the apical meristem. They described that pinching of ‘Sun Bright’ after three weeks of planting produced a crop with uniform stems about 91 cm long, whereas the non-pinched stems grew up to a length of 152 cm. Pinching should be done as early as possible (Wien, 2016). Delayed pinching after the emergence of the buds will result in weaker and shorter stem length. Armitage and Laushman (2003) stated that smaller flower size with suitable stem length is the result of successful pinching. Smaller head size and suitable stem length will allow florists to use them in a variety of arrangements. Those growers who are interested in pinching should grow branching and single stem cultivars for the sake of increasing profit (Wien, 2016). Wien (2016) demonstrated that pinching of sunflower cultivars at the right time increases yield by three to four times. After years of successfully conducted experiments on sunflower, Wien (2016) comes to the conclusion that the worth of flowers per unit area decreases as flower size increases. He concluded that pinching increases the number of smaller head sunflowers thus resulting in an increase of profits for growers (Wien, 2016).

Drawbacks of Pinching

There are also drawbacks to pinching. The pinching process delayed formation of flowers by 7 to 10 days (Wien, 2006). Pinching is a time consuming and costly process. Although pinching doubles the number of flowers, in some cultivars pinching causes a reduction in flower size and stem length, thus making them unmarketable (Wien, 2006). Wien (2006) stated that the stems that are harvested from pinched plants wilted readily and had shorter vase and postharvest life. Mechanical injury caused to the leaves as a result of pinching negatively affects the production and quality of the sunflowers (Wien, 2013). Wien also stated that there is a need to find a more convenient way of pinching in order to prevent injury. Pinching results in the crowding of branches within the same area which results in reduced flower and disk diameters. Stem length and flower diameter were reduced to half that of the non-pinched plants (Wien, 2013).

Spacing

Sunflowers are grown both as an agronomic and specialty cut flower crop. Plant spacing is one of the main production factors to ensure optimum plant density while producing high quality sunflowers. The spacing of sunflowers depends on the purpose of the crop, agronomic or horticultural.

Agronomic spacing

While growing sunflower as an agronomic crop, optimum plant spacing and density are important factors that increase yield. It is reported that decreasing spacing between rows with equal plant densities will also decrease plant-to-plant competition for sunlight and biomass production (Andrade et al., 2002; Bullock et al., 1988). Results have varied with the planting pattern; some researchers indicated that differences in planting patterns result in high yield (Ikeda and Sato, 1992; Robinson et al., 1980). Some researchers found no clear yield differences (Nishri, 1976; Wiggans, 1939; Wilocox, 1974). Ogunremi (2000) stated the optimum plant population for sunflower crops is 55,000 plants per hectare if it is grown as a sole crop. However, increased yields have been obtained with sunflower by increasing the plant population from 17,000 plants to 90,000 plants per hectare (Massey, 1971).

Sunflowers are grown as a row crop. The row width changes with the availability of equipment. Optimum results can be obtained when the width between rows is 50-76 cm; however, good yields can be obtained if the width is as narrow as 35 cm and as wide as 101 cm. Row spacing should be done in correspondence with the harvesting equipment. The number of plants per hectare should remain the same regardless of the width of the row. The differences in sunflower population are compensated by the production of larger heads and seeds at low plant population (Warrick, n.d). Sunflower plant populations should be in the range of 37,050 to 54,340 plants per hectare for oil seed cultivars. For the non-oil cultivars the plant population should be in the range of 29,640 to 44,460 plants per hectare. In an experiment conducted by Beg et al. (2007), row spacing treatments were 50-75 cm and within row plant spacing treatments were 20, 25, 30, and 35 cm. This combination of plant and row spacing resulted in plant populations of 38,000-100,000 plants per hectare (Beg et al., 2007), which ultimately resulted in higher yield.

Horticultural Spacing

Cut flowers are frequently produced on beds. Wien (2012a) suggested that a bed width of 122 cm is more suitable for growing sunflower as a cut flower for different spacing and pinching treatments. Wien (2008) conducted an experiment on two cultivars of sunflowers, ‘Pro Cut Orange’ and ‘Sunrich Orange’. These two cultivars were planted at a spacing of 23 × 23 cm with 4 rows per bed and 30 × 30 cm with 3 rows per bed. Wien pinched these trials which delayed flowering by 5 days. The act of pinching increased the number of stems from 1 to 2.6 with reduced flower diameter and stem length, whereas for increased spacing the flower diameter and stem length increased (Wien, 2008). Wien (2012b) conducted an experiment on a 122 cm wide bed with three different spacing treatments, 15 × 15 cm, 23 × 23 cm, and 30 × 30 cm, with 6, 4, and 3 rows, respectively, per bed. Some of these treatments were pinched, and some were non-pinched. The pinched treatments reduced stem lengths up to 50%, but these stems were still marketable. The closely spaced treatments produced reduced flower and disk diameters that were not marketable.

Insects, Pests and Diseases

There are more than 91 diseases of sunflower that have been reported throughout the world (Bai et al., 1985). Fungi and bacteria are infectious microorganisms that attack sunflowers; result in the loss of yield and quality (Ara et al., 1996). Yield and quality loss depends on the onset of disease and intensity of the infection. The majority of sunflower diseases are caused by fungi. Alternaria blight (*Alternaria)*, Verticillium wilt *(Verticillium dahlia)*, Downy mildew *(Plasmopara halstedii)*, Charcoal rot (*Macrophomina phaseolina)*, Rust *(Puccinia helianthi),* Sclerotinia stalk or head rot (*Sclerotinia sclerotiorum)* are the main diseases. To maximize production, diseases need to be controlled. These diseases affect the flower head and stem, thus resulting in damage to the crop whether it is grown as an agronomic or specialty cut flower crop. Sunflower crops that are grown for oil purposes stay longer in the field as compared to the crops grown as cut flowers; therefore, more is known about the pests that affect agronomic crops (Stevens et al., 1993). Pests that affect the flower disk and foliage are important for the production of the cut flower as these parts are important for selling the sunflower as a cut flower. Pests like caterpillars, long-horned beetles, and deer play a significant role in decreasing the aesthetic value of the crop by damaging the foliage (Stevens et al., 1993).

Photoperiod

Day length profoundly affects plant size, flower diameter, disk diameter, and flowering date in the first three weeks after the emergence of sunflower seedlings. Various sunflower cultivars respond differently to photoperiod (Wien, 2008). Wien (2008) determined that many sunflower cultivars are sensitive to day length. Day length sensitive cultivars start flowering much earlier if they are exposed to 12 h day length versus 16 h day length for the first three weeks after emergence. An experiment conducted by Wien (2011) determined that 'Pro Cut Lemon' is a day neutral cultivar and showed no differences in characteristics when exposed to short day and long day treatments, whereas 'Sunrich Orange' is sensitive to the day length. This cultivar flowered 10 days earlier after short day versus long day treatment. 'Superior Gold', 'Vincent's Choice', 'Sun Bright Supreme', and 'Sunrich Lemon' are facultative short day cultivars (Ha, 2014; Hayata and Imaizumi 2000; Wien 2014a; 2014b). 'Pro Cut Gold' is a day neutral cultivar. Those cultivars that are sensitive to day length start flowering much earlier if they are exposed to 12 h day length. Wien (2014a; 2014b) explained that day neutral plants were not affected by the photoperiod. Short day cultivars start flowering earlier in response to short days (Wien, 2015; Blacquiere et al., 2002).

Effect of sunlight

Light plays an important role in photosynthesis. The process of photosynthesis is carried out using light of specific wavelengths (400 to 700 nm). Photosyntheticaly active radiation (PAR) is captured by the pigments including chlorophyll a, chlorophyll b, carotenoids and other accessory pigments, which ultimately transfer the energy to the photosynthetic reaction centers (Nishio, 2000). The productivity of sunflower per unit area is determined by various factors including cultivar and plant density. Optimum above ground conditions for plant populations allow the crop to absorb essential resources that are helpful for growth (light, nutrients etc.), thus affecting flower size and stem diameter (Ibrahim, 2012). The competition for nutrients, water, and PAR become more intense under dense plant population. The planting density not only changes the availability of resources but also generates photomorphogenic signals (Libenson et al., 2002). The red light/far-red light (R/FR) ratio signal is established earlier in densely populated crops as compared to less densely populated crops (Ballare et al., 1987). This signal reaches the stem of the seedlings where it is perceived by phytochromes and promotes stem elongation (Ballare et al., 1987, 1988). The amount of R/FR light reaching the stem of the crop is reduced by increasing plant densities, with a continuous increase in stem length observed (Libenson et al., 2002). The increase in stem length due to reduced R/FR ratio could reduce the available resources for the growth of harvestable organs (Ballare et al., 1992, Smith, 1992; Sanchez et al., 1993; Ballare and Casal, 2000). The low R/FR light ratio causes increased dry matter allocation to the stem (Trapani et al., 1994); reduced flower size could be the consequence of competition for resources between the stem and the head. The number of leaves per plant, date of flowering, and date of anthesis were not affected by the R/FR conditions (Libenson et al., 2002). Mutual shading in densely populated crop reduces the activity of photosensory receptors such as phytochromes and cryptochromes, as a result the absorption of light by photosynthetic pigments reduces the R/FR ratio perceived by phytochromes and blue light irradiance perceived by cryptochromes (Pereira et al., 2017). Research conducted by Ibrahim (2012) showed that increased plant densities lead to a decrease in leaf area per plant, delayed flowering and reduced flower size. These results could be explained on the basis of inter-plant competition for light and other resources. High plant densities also resulted in an increase in stem length of sunflowers (Ibrahim, 2012).

Temperature

Sunflowers can be grown in semiarid regions throughout the world. Sunflowers can tolerate both high and low temperatures but are more tolerant of low temperatures. Sunflower seeds can germinate at 4°C but for satisfactory germination temperatures of at least 7-10°C are required. Optimum temperatures for the growing of sunflowers are 21-25°C, but wider temperature ranges of 17-32°C have little effect on productivity (Putnam et al., 1990).

Marketing Standards for Sunflower

There are no defined parameters for the marketing standards of sunflower in terms of flower size and stem length. Sloan and Harkness (2010) after interviewing florists in Tupelo, Mississippi, stated that the optimum length of sunflower stems is 60-90 cm. Stem diameters of 0.5-1.5 cm and flower diameters of 8-15 cm are preferred. The standard requirement for marketable disk diameter is 4 cm (Wien, 2016; Wien, 2017). There are certain standards set by the AFIF and Ascolflores (2009). According to these standards flowers that are of size 10 cm are ‘extra’, 8-10 cm are ‘select’, 5-8 cm are ‘fancy,’ and less than 5 cm are ‘petite’. AFIF and Ascolflores (2009) suggested the minimum stem length to be no less than 55 cm. The minimum standards used for the following experiments were a stem length of 60 cm, stem diameter of 5 mm, flower diameter of 8 cm, and disk diameter of 4 cm (Wien, 2016; 2017; Sloan and Harkness, 2010).

EXPERIMENT 1: Trials 1A and 1B: Effect of pinching on the growth and development of sunflowers (*Helianthus annuus*).

Introduction

Growers are using the technique of pinching on single stem sunflower cultivars to cause branching, increasing the number of flowers produced while maintaining a marketable quality product. Pinching, also known as tipping, is a method of pruning that is used in growing plants at early stages to encourage branching. Pinching plays an important role in increasing the yield and extending the bloom period. It can become an important strategy for growers. The main purpose of pinching is to force the plant to grow more stems from the point below the pinched stem. By pinching before the plant starts flowering, the plant is stimulated to produce more branches that will produce flowers.

There are certain hormones that help in the control of apical dominance, namely auxin, cytokinin and strigolactones (Leyser, 2009; Morris et al., 2005). Without pinching there will be no development of lateral branches. Different cultivars of sunflower react differently to the phenomenon of pinching; currently there is no specific guideline for pinching available. Pinching should be done as early as possible after planting to enhance the number of stems and flowers.

The practice of pinching should be done after careful observation to determine whether it will be beneficial or detrimental for the producer. Wien (2016) demonstrated that pinching increases the yield of sunflower by three to four times. The practice of pinching allows the grower to produce more flowers with suitable stem length and flower size (Armitage and Laushman, 2003). Smaller head size with suitable stem length will allow florists to use the flowers in a variety of arrangements.

Along with advantages there are also draw backs of pinching. Wien (2006) stated that pinching delays blooming by 7 to 10 days. There is no doubt pinching is helpful in increasing the number of flowers and stems per plant but in some cultivars it causes reduction and deformation of the flowers, thus making them unmarketable (Wien, 2006). The objective of this research is to determine how pinching sunflowers at different nodes with the same spacing affects stem length, stem diameter, flower diameter, disk diameter, days to harvest, stems per plant, and number of marketable stems.

Material and Methods

Trials (1A and 1B) were conducted at Stephen F. Austin State University in Nacogdoches Texas. The experimental area that was used for these trials was an open area between the SFASU Soccer Field and La Nana Creek. The dimensions of the raised beds were 121 × 365 × 61 cm. Soil analysis was performed to check the amount of nutrients present in the raised beds (Table 1.1). The pH for these raised beds was 7.59 (for trial 1A) and 7.67 (for trial 1B), which was within the range of 5.7 to 8.0 optimal for sunflowers (Putnam et al., 1990). The beds were prepared for planting on 20 April 2017 for trial 1A and for trial 1B on 2 August 2017. This experiment had 5 pinching treatments at nodes 0, 1, 2, 3, and 4 and five sunflower cultivars: 'Superior Gold', Pro Cut Gold', 'Sun Bright Supreme', 'Vincent's Choice', and 'Sunrich Lemon' (Table 1.2). Seeds were sown directly in the raised beds at a distance of 23 × 23 cm on 28 April 2017 for trial 1A and on 3 August 2017 for trial 1B. Two seeds at each location were sown and following germination thinned to 1 plant. Sowing was done on 10 raised beds. Each bed was split up into two sub-beds and each sub-bed had one cultivar with 5 rows. Each of the 5 rows was randomly assigned one of the 5 pinching treatments. The number of plants for each treatment was 20.

Table 1.1. Soil analysis data for trial 1A and 1B with sufficiency ranges.

Nutrients	Raised bed (1A) (ppm)	Raised bed (1B) (ppm)	Sufficiency range (ppm)
NO_3	15	1	100-199[z]
P	269	195.66	21-60[y]
K	198	84.64	120-300
Ca	8177	6260.63	460-749
Mg	180	126.04	100-150
S	34	25.72	16-25
Fe	108	22.73	2.5-4.5
Mn	5.7	3.30	1-1.5
Zn	2.6	3.61	0.3-0.8
Cu	0.54	2.55	0.1-0.3

[z] Sufficiency range of a saturated media from Greenhouse Operation and Management (Nelson, 2012).
[y] Sufficiency ranges of soil from Stephen F. Austin State University Lab.

Thinning and transplanting were done on 10 May 2017 for trial 1A and on 12 August 2017 for trial 1B. Beds were fertilized on the same day with Lone Star Super Lawn and Turf Builder 15N-2.2P-8.3K (Texas Farm Products Co, Nacogdoches, TX) at a rate of 63 g per m^2. This fertilizer had additional nutrients with percentages listed: S (13.4%), B (0.02%), Cu (0.05%), Fe (1.0%), Mn (0.05%), Mo (0.0005%) and Zn (0.05%). Beds were irrigated with drip irrigation every other day for the duration of the trials except the days it rained.

Table 1.2. Characteristics of the five cultivars taken from Gloeckner Seed Catalog.

Cultivar	Comments	Photoperiodic Response[z]	Flower Color	Stems	Days to Harvest (d)	Plant Height (m)	Flower Diameter (cm)[y]
'Superior Gold'	Fall and Shorter Days	Facultative Short day	Golden yellow	Single	60	1.5-1.8	15-20
'Pro Cut Gold'	Spring Summer, Fall	Day neutral	Golden orange	Single	60	1.2-1.8	10-15
'Sun Bright Supreme'	Year Round	Facultative Short day	Golden yellow	Single	55	1.2-1.5	15-20
'Vincent's Choice'	Day Length Neutral, all seasons	Facultative Short Day	Golden yellow	Single	55	1.2-1.5	10-15
'Sunrich Lemon'	Spring, Summer, Fall	Facultative Short day	Lemon yellow	Single	55-70	0.9-1.5	10-15

[z] Data from Wien, 2014a; 2015
[y] Flower size from Gloeckner Seed 2016-2017 Catalog.

For trial 1A, pinching was done on 17 May 2017, 25 May 2017, 1 June 2017 and 5 June 2017 at nodes 1, 2, 3, and 4, respectively. For trial 1B, pinching was done on 16 August 2017, 19 August 2017, 23 August 2017 and 25 August 2017 at nodes 1, 2, 3 and 4, respectively. The control plants were not pinched.

Sunflowers were harvested when the sunflower heads were fully developed and open. Stem length for the control plants was measured from the base of the flower to the ground, whereas for the pinched treatments stem length was measured from the point where branching occurred. Additional measurements recorded were stem diameter (approximately 2.5 cm below the flower), flower diameter, disk diameter, and harvest date. The minimum standards used for trials (1A and 1B) were a stem length of 60 cm, stem diameter of 5 mm, flower diameter of 8 cm and disk diameter of 4 cm (Wien 2016; 2017; Sloan and Harkness, 2010). If the flowers didn't meet the above mentioned requirements they were classified as unmarketable.

The experimental design was a randomized complete block design with four replicates. The data was analyzed using SAS 9.2 (Cary, NC) via Two-Way ANOVA. Tukey's Studentized Range Test was used to test for significant differences between means at a 5% probability level.

Results

Trial 1A: Effect of pinching treatments on 'Superior Gold', 'Pro Cut Gold', 'Sun Bright Supreme', 'Vincent's Choice', and 'Sunrich Lemon', sunflowers (*Helianthus annuus*).

There was a significant interaction for stem length between cultivars and treatments (Table 1.3). All five cultivars showed a similar trend with stem length decreasing as node pinched increased from node 0 to node 4. Stem length also decreased depending on the vigour of each cultivar, resulting in a significant cultivar by pinching interaction. The non-pinched sunflowers for all five cultivars had significantly greater stem length as compared to pinched treatments. Although pinching and lower cultivar vigour resulted in shorter stem lengths, all cultivars and pinched treatment combinations produced marketable stem lengths of ≥ 60 cm.

For stem diameter there was a significant interaction between cultivars and pinching treatments (Table 1.3). There was a general trend of stem diameter decreasing as the node pinched increased. Likewise the stem diameter decreased as vigour of the individual cultivars decreased, resulting in a significant cultivar by pinching interaction. Stem diameter of pinched sunflowers was significantly reduced as compared to the non-pinched sunflowers regardless of cultivar. For 'Superior Gold' and 'Pro Cut Gold' all pinching treatments produced marketable stem diameters, whereas 'Sun Bright

Table 1.3. Effect of pinching sunflowers (*Helianthus annuus*) ‘Superior Gold’,‘ Pro Cut Gold’, ‘Sun Bright Supreme’, Vincent’s Choice’, and ‘Sunrich Lemon’ on stem length, stem diameter, flower diameter, disk diameter, days to harvest, stems per plant and marketable stems for trial 1A.

Cultivar	Pinch (node)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)	Marketable stems (no.)
‘Superior Gold’	0	218.44a[z]	13.10a	18.97a	9.60a	69.41c	1.00b	1.00a
	1	135.31b	6.31b	12.31b	5.40b	70.95b	2.00a	1.60a
	2	137.35b	6.19b	11.71b	5.04b	73.18a	2.25a	1.60a
	3	129.71b	6.74b	11.35b	5.05b	76.76a	1.84a	1.57a
	4	99.11c	5.51b	10.99b	4.53b	74.41a	1.70a	1.05a
‘Pro Cut Gold’	0	160.65a	11.18a	17.68a	8.43a	53.15d	1.00c	1.00bc
	1	88.15b	7.03b	13.15b	5.25b	58.17c	2.01a	1.65a
	2	75.72bc	6.25b	10.59c	4.45bc	61.55b	2.00a	1.20ab
	3	75.39bc	6.27b	10.37c	4.10c	66.02a	1.73ab	0.84bc
	4	63.62c	6.23b	9.89c	3.77c	67.14a	1.11bc	0.58c
‘Sun Bright Supreme’	0	167.05a	13.41a	17.32a	8.85a	68.85d	1.00c	1.00b
	1	124.68b	6.68b	11.24b	5.34b	72.78c	1.78b	1.26b
	2	129.25b	6.28b	10.80bc	5.10bc	75.26b	2.78a	2.05a
	3	109.38b	4.51c	8.90c	4.13bc	79.56a	2.50a	1.00b
	4	88.49c	4.66c	8.76c	3.90c	78.15a	1.70b	0.80b
‘Vincent’s Choice’	0	153.52a	11.65a	16.11a	8.48a	57.16c	1.00c	1.00ab
	1	84.33b	5.49bc	10.14b	4.97b	60.86b	2.00b	1.25ab
	2	80.58bc	5.99b	10.19b	4.59bc	60.48b	3.10a	1.75a
	3	73.85c	5.00bc	9.40b	4.51bc	66.19a	3.35a	1.60ab
	4	63.44d	4.80c	8.93b	3.86c	67.47a	2.80ab	0.75b
‘Sunrich Lemon’	0	141.86a	11.15a	16.19a	9.47a	68.89c	1.00c	1.00a
	1	86.35b	5.34b	10.09b	4.36b	74.15a	1.68a	0.84a
	2	69.86c	4.90b	9.03b	3.66bc	71.54b	1.50abc	0.50b
	3	77.37bc	4.58b	9.05b	3.86bc	74.85a	1.60ab	0.80a
	4	63.05c	4.13b	8.35c	3.27c	75.10a	1.10bc	0.25b
Statistical Significance	Cultivar	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001
	Pinch	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Interaction	<0.0001	<0.0001	0.4553	0.0006	<0.0001	<0.0001	0.0007

[z] Means within column for each cultivar followed by the same letter are not significantly different at the 5% probability level by Tukey’s Studentized Range Test.

Supreme', 'Vincent's Choice', and 'Sunrich Lemon' failed to produce marketable stem diameters when pinched at nodes 3-4, 4, and 2-4, respectively.

For flower diameter there was no significant cultivar by pinching interaction (Table 1.3). There was a significant reduction in flower diameter for all pinched treatments as compared to the non-pinched sunflowers. There was a general trend that as the node pinched increased the flower diameter decreased for all five cultivars. However, the trend was only significant for 'Pro Cut Gold', 'Sun Bright Supreme', and 'Sunrich Lemon'. Irregardless of cultivar or pinching treatment all treatment combinations produced marketable flower diameters.

There was a significant interaction between cultivars and pinching treatments for disk diameter (Table 1.3). All five cultivars showed a consistent trend that as the node pinched increased, there was a reduction in disk diameter. Depending on the cultivar there was variation in disk diameter resulting in a significant cultivar by pinching interaction. Similar to flower diameter, disk diameter was significantly reduced as compared to the non-pinched sunflowers. Only the 'Superior Gold' sunflowers produced marketable disk diameters ($\geq$ 4cm) for all pinching treatments. Cultivars 'Pro Cut Gold', 'Sun Bright Supreme', and 'Vincent's Choice' failed to produce marketable disk diameters when pinched at node 4. 'Sunrich Lemon' had marketable disk diameters when pinched at node 1.

For days to harvest there was a significant interaction between cultivars and pinching treatments (Table 1.3). Unlike previous parameters, days to harvest increased as the node pinched increased ranging from 5 to 12 days depending on cultivar. Days to harvest varied depending on cultivar resulting in a significant cultivar by pinching interaction.

A significant interaction was observed between cultivars and pinching treatments for the number of stems per plant (Table 1.3). There was somewhat of a normal distributed curve related to node pinched with the number of stems produced peaking at node 1 or 2 and then declining at nodes 3 and 4. The number of stems produced as a result of pinching varied depending on the cultivar, resulting in a significant cultivar by pinching interaction

For marketable stems there was also a significant interaction between the cultivars and the pinching treatments (Table 1.3). The number of marketable stems varied depending on cultivar. The general trend for pinching was an increase in the number of marketable stems with pinching that declined as the node pinched increased, producing a significant cultivar by pinching interaction. Only the 'Sun Bright Supreme' pinched at node 2 produced more than 2 marketable stems per plant. 'Sunrich Lemon', the least vigorous cultivar failed to produce even 1 marketable stem for all pinched treatments.

Results

Trial 1B: Effect of pinching treatments on 'Superior Gold', 'Pro Cut Gold', 'Sun Bright Supreme', 'Vincent's Choice', and Sunrich Lemon sunflowers (*Helianthus annuus*).

For stem length there was a significant interaction between the cultivars and pinching treatments (Table 1.4). There was no consistent trend among the five cultivars related to stem length, except that all the non-pinched treatments were significantly longer than the pinched treatments. Stem length also decreased with decreasing vigour of the cultivar, resulting in a significant cultivar by pinching interaction. All pinching by cultivar treatment combinations produced marketable stem lengths of $\geq$ 60 cm.

There was a significant interaction between cultivars and pinching treatments for stem diameter (Table 1.4). The general trend of stem diameter decreasing as the node pinched increased was not observed. However, the stem diameter of non-pinched plants was significantly larger than pinched plants for all five cultivars. Stem diameter decreased with decreasing vigour of the cultivar, resulting in a significant cultivar by pinching interaction. The non-pinched treatments produced significantly larger stem diameter as compared to the pinched treatments regardless of cultivar.

Table 1.4. Effect of pinching sunflowers (*Helianthus annuus*) ‘Superior Gold’,‘ Pro Cut Gold’, ‘Sun Bright Supreme’, Vincent’s Choice’, and ‘Sunrich Lemon’ on stem length, stem diameter, flower diameter, disk diameter, days to harvest, stems per plant and marketable stems for trial 1B.

Cultivar	Pinch (node)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)	Marketable stems (no.)
‘Superior Gold’	0	198.75a[z]	11.20a	15.88a	7.33a	51.20d	1.00b	1.00a
	1	105.93c	4.99b	10.84b	4.80b	58.15c	2.23a	0.76a
	2	133.47b	5.78b	11.17b	4.54b	61.92b	2.30a	1.38a
	3	125.68b	5.42b	10.90b	4.33b	63.72b	2.27a	1.33a
	4	122.40bc	5.34b	10.93b	4.20b	66.20a	1.80a	1.06a
‘Pro Cut Gold’	0	131.48a	11.21a	16.39a	7.11a	49.35d	1.00c	1.00a
	1	84.87c	6.71b	8.27b	3.76b	55.58c	2.33a	0.33b
	2	102.40b	5.27b	9.95b	4.31b	57.81bc	2.90a	1.09a
	3	96.70bc	5.64b	9.27b	3.92b	60.99ab	2.35a	0.82b
	4	102.47b	5.25b	10.22b	4.17b	64.14a	1.35b	0.92b
‘Sun Bright Supreme’	0	142.96a	11.35a	15.69a	8.50a	56.78d	1.00c	1.00a
	1	95.81b	4.08b	9.01b	3.70b	61.91c	1.83ba	0.58a
	2	100.38b	5.00b	10.57b	4.22b	64.50b	2.08a	0.60a
	3	113.51b	5.04b	10.06b	4.06b	65.58b	2.00ab	0.75a
	4	103.52b	5.05b	9.73b	4.01b	67.81a	1.27b	0.90a
‘Vincent’s Choice’	0	132.67a	10.48a	13.89a	6.38a	50.29c	1.00c	1.00ab
	1	92.45b	4.14b	7.42c	3.60c	57.70b	2.40a	0.20c
	2	97.32b	5.25b	10.12b	4.76b	59.63b	2.36a	0.72b
	3	98.48b	5.22b	9.12bc	4.44bc	59.72b	2.27ab	0.63bc
	4	95.17b	4.67b	8.40bc	4.60bc	67.25a	1.50bc	1.37a
‘Sunrich Lemon’	0	132.54a	10.21a	13.36a	6.04a	50.90c	1.00b	1.00a
	1	77.08c	5.06c	8.84bc	4.19b	60.83b	1.66ab	1.16a
	2	101.94b	6.75b	10.90b	4.79b	67.91b	2.00a	1.41a
	3	84.62c	5.42bc	8.56c	3.97b	69.18ab	2.00a	1.00a
	4	84.93c	5.46bc	9.65bc	4.87b	71.00a	1.54ab	1.72a
Statistical Significance	Cultivar	<0.0001	<0.0001	<0.0001	0.2740	<0.0001	0.0059	0.0067
	Pinch	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Interaction	<0.0001	<0.0001	0.0257	<0.0001	<0.0001	0.2832	0.1106

[z] Means within column for each cultivar followed by the same letter are not significantly different at the 5% probability level by Tukey’s Studentized Range Test.

For ‘Pro Cut Gold’ and ‘Sunrich Lemon’ all pinching treatments produced marketable stem diameters whereas, ‘Superior Gold’ and ‘Sun Bright Supreme’ failed to produce marketable stem diameters when pinched at node 1, and ‘Vincent’s Choice’ at nodes 1 and 4.

There was a significant interaction between cultivars and pinching treatments for flower diameter (Table 1.4). All five cultivars followed a general trend of flower diameter decreasing as the node pinched increased. All non-pinched treatments produced significantly larger flower diameter as compared to the pinched treatments. All pinching treatments of the cultivars ‘Superior Gold’, ‘Pro Cut Gold’, ‘Sun Bright Supreme’ and ‘Sunrich Lemon’ produced marketable flower diameters. ‘Vincent’s Choice’ failed to produce a marketable flower diameter when pinched at node 1.

For disk diameter, there was a significant interaction between cultivars and pinching treatments (Table 1.4). The five cultivars failed to show a consistent trend of disk diameter decreasing as the node pinched increased. Similar to stem diameter and flower diameter, disk diameter was significantly larger for the non-pinched sunflowers compared to the pinched treatments. Only ‘Superior Gold’ produced marketable disk diameter for all the pinching treatments. ‘Sun Bright Supreme’ and ‘Vincent’s Choice’ failed to produce marketable disk diameter at node 1. ‘Pro Cut Gold’ at nodes 1 and 3 and ‘Sunrich Lemon’ at node 3 failed to produce marketable disk diameters.

Of the parameters evaluated days to harvest resulted in the most consistent trend with days to harvest increasing as node pinched increased (Table 1.4). The difference in number of days to harvest ranged from 6 to 21 days for pinching at 0 to 4 depending on the cultivar, resulting in a significant cultivar by pinching interaction.

There was no significant interaction between cultivars and pinching treatments for the number of stems per plant (Table 1.4). There was somewhat of a normally distributed curve related to node pinched with the number of stems produced peaking at nodes 1 or 2 and then declining at nodes 3 and 4. The number of stems produced as a result of pinching varied depending on the cultivar. All of the cultivars by pinching treatments produced fewer than 2.5 stems per plant except for ‘Pro Cut Gold’ at node 2.

There was no significant interaction between cultivar and pinching treatments for the number of marketable stems (Table 1.4). Even though there was a significant difference for pinching treatments, only ‘Pro Cut Gold’ and ‘Vincent’s Choice’ resulted in a significant difference between node pinched with most pinched treatments resulting in fewer marketable stems than the non-pinched treatment. There was also a significant difference between cultivars. Interestingly, ‘Superior Gold’ and ‘Sunrich Lemon’ the most vigorous and least vigorous cultivar, respectively averaged the highest number of marketable stems compared to the other cultivars.

Discussion

Similar to previous research all the pinching treatments produced smaller stem lengths as compared to the non-pinched treatments for both trials 1A and 1B (Burnett, 2017; Wien 2015). There was a general trend that as the node pinched increased stem length, stem diameter, flower diameter and disk diameter decreased for both trials 1A and 1B, similar to previous research (Burnett, 2017; Sloan and Harkness, 2010; Wien, 2015). All the cultivars in both trials 1A and 1B with pinched treatments produced marketable stem lengths (Tables 1.3 and 1.4), whereas Burnett (2017) found that only 'Superior Gold' sunflowers produced marketable stem lengths. Similarly to Wien (2015), most pinching treatments of the cultivar 'Vincent's Choice' and 'Sun Bright Supreme' produced marketable flower and disk diameters for both trials 1A (Table 1.3) and 1B (Table 1.4) whereas Burnett (2017) failed to produce marketable disk diameters.

Conversely, days to harvest and number of stems for both trials 1A (Table 1.3) and 1B (Table 1.4) increased as the node pinched increased, which is consistent with previous research (Burnett, 2017; Wien, 2015).

After conducting numerous experiments Wien (2015) concluded that cultivars responded differently to the pinching treatments but overall decreased stem length and disk diameter resulted from pinching at node 3, similar to the results of Trials 1A and 1B, and further decreased with pinching at node 5.

Wien (2015) observed that marketability of the stems decreased with pinching at node 5 whereas in pinching trials 1A and 1B in this study marketability of the stems decreased with pinching at node 4. Results of trials 1A and 1B were similar to those of Wien's (2015) observations, that pinching significantly reduced stem length, flower diameter, and disk diameter even though stem length and flower diameter of the pinched treatments met standard market requirements, whereas Burnett (2017) conducted an experiment in the fall and found that pinching reduced stem length and disk diameter to the point where they were not marketable.

Different sunflower cultivars behave differently to photoperiod (Wien, 2008). 'Pro Cut Gold' is a day neutral cultivar. 'Superior Gold', 'Vincent's Choice', 'Sun Bright Supreme' and 'Sunrich Lemon' are facultative short day cultivars (Ha, 2014; Hayata and Imaizumi 2000; Wien 2014a; 2014b). Those cultivars that are sensitive to day length start flowering much earlier if they are exposed to 12 h day length. Short day cultivars produced long stems and bigger flower sizes under short day conditions. Wien (2014a; 2014b) explained that day neutral plants were not affected by photoperiod. Short day cultivars start flowering earlier in response to short days (Wien, 2015; Blacquiere et al., 2002). All five cultivars required more days to harvest in trial 1A as compared to the trial 1B.

In trial 1A pinched treatments followed the trend of 'Superior Gold' being most vigorous and producing longer stems length followed by 'Sun Bright Supreme', 'Pro Cut

Gold', 'Vincent's Choice', and 'Sunrich Lemon' (Table 1.3). In trial 1B 'Superior Gold' produced longer stems followed by 'Sun Bright Supreme', 'Vincent's Choice', 'Pro Cut Gold' and 'Sunrich Lemon', respectively (Table 1.4).

Day length affects plant size, flower diameter, disk diameter and flowering date in the first three weeks after the emergence of the sunflower seedlings. The cultivar 'Sun Bright Supreme' during short days is sensitive in the seedling stage (Dole et al., 2012). Pallez et al. (2002) found that during long days of 16 h or more plants remained in the vegetative phase which resulted in an increase in stem length prior to flower initiation. Trial 1A was conducted in late April to early May in USDA hardiness zone 8. At that time the day length in Nacogdoches was 13 h 22 min in May increasing to 14 h 2 min in July (Rise and Set for the Sun for 2017).

Trial 1B was conducted in early August in zone 8. Day length at that time was 13 h 39 min decreasing in October to 11 h 50 min (Rise and Set for the Sun for 2017). Burnett (2017) conducted an experiment at the end of August in Nacogdoches. At that time the day length was 12 h 53 min in August decreasing to 10 h 41 min in November. Wien (2015) conducted experiments on sunflower cultivars in Ithaca, New York during the months of May to August. At that time the day length was 14 h 46 min in May increasing to 15 h 3 min in June and then decreasing in July to 14 h 40 min and in August to 14 h 24 min.

For trials 1A and 1B the results were similar to those of Wien's (2015) experiments. Few pinching treatments of cultivars failed to produce marketable disk diameter and stem diameter. This might be due to some environmental factors such as temperature and day length. There was also Hurricane Harvey during trial 1B. For one week there was continuous rain, totaling 16.7 cm, and limited sunlight.

Temperature could be one of the factors contributing to differences in results. Wien (2015) conducted experiments at the end of May. At that time the average temperature was 16°C in May, 20°C in July, and then decreased to 18 °C in August. During Burnett's (2017) experiment, the average temperature was 28 °C, 25 °C, 19 °C, 16°C in August, September, October, and November, respectively. During trial 1A that was conducted at the end of April the average temperature was 20 °C, 24 °C, and 27 °C in May, June and July, respectively, whereas for trial 1B the temperature was 30 °C , 25 °C and 22 °C in August, September, and October, respectively. Temperature could be one of the reasons for early flower development in trial 1B as compared to the trial 1A. This early development of flowers due to temperature also affects stem length, stem diameter, flower diameter, and disk diameter. Prior research (Goyne and Schneiter, 1988; Haba et al., 2014; Lokhande et al., 2003) has shown that temperature plays an important role in the development of sunflowers. High temperature could be the reason for early flowering and smaller flower size (Vince-Prue, 1975). In *Arabidopsis thaliana* the initiation of flowering started earlier under high temperature, whereas under low temperature *Arabidopsis thaliana* delayed flowering (Lokhande et al., 2003). Under high temperature faster flower initiation does not allow the flower to develop normally, thus resulting in smaller flowers disk (Lokhande et al., 2003). Armitage and Laushman (2003) reported that the optimum temperature range for the growth and development of the sunflower is 18-24°C. High temperature causes a reduction in plant growth (Armitage and Laushman, 2003). Goyne and Schneiter (1988) in a growth chamber experiment observed that high day/night temperatures of 28/22 °C initiated earlier flower development and longer stem length as compared to sunflowers grown at 18/15°C. They concluded that the high temperature initiated early flower development with longer stem length. However, day/night temperatures of 33/29°C resulted in a reduction in photosynthesis that decreased plant growth under high temperatures (Haba et al., 2014).

The phenomenon of pinching increased the number of stems per plant. Sunflower cultivars respond differently to the pinching in terms of the number of stems produced. For both trials (1A and 1B) all the pinched treatments of all cultivars produced more than 1 stem on average and some even produced 2 stems per plant. Burnett (2017) and Wien (2015) produced 3 to 4 stems per plant on average. However, in terms of marketable stems, trials 1A and 1B produced more marketable stems as compared to Burnett (2017) but much fewer than the 3 to 4 marketable stems of Wien (2015).

Conclusion

Cultivars of sunflower reacted differently to the pinching treatments for both trials 1A and 1B. All the non-pinched treatments in both trials produced longer stem length, larger stem diameter, flower diameter, and disk diameter as compared to the pinched treatments. Non-pinched plants were harvested earlier in both trials as compared to the pinched treatments. Pinching treatments of both the trials produced more stems per plant as compared to the non-pinched treatments.

Trail 1A conducted in late spring produced more marketable stems than trial 1B conducted in late summer. Both trials 1A and 1B showed that higher cultivar vigour increased marketable sunflowers. For both trials 1A and 1B pinching at node 2 typically produced the greatest number of marketable stems. Based on the limited data from this experiment, if pinching sunflowers, it must be on spring plantings with vigorous sunflower cultivars at node 2 to increase the number of marketable sunflowers. This research suggests that pinching of sunflowers during late summer in East Texas is not beneficial for increasing sunflower yield

EXPERIMENT 2: Effect of plant spacing on sunflowers (*Helianthus annuus*).

Introduction

Plant spacing is one of the main production factors for any crop to ensure optimum plant density and to minimize the losses that occur as a result of overcrowding. The plant population affects the cost of planting. Sunflowers are grown both as an agronomic crop and specialty cut flower crop. Specialty cut flower growers are more interested in stems and flower sizes whereas for agronomic purposes growers are interested in seeds for the production of oil. For the production of cut flowers, growers are striving to pick a spacing that will produce marketable flowers by utilizing the available space. Previous research has shown that plants should be spaced 15-30 cm within rows and 45-91 cm between rows. With the above-mentioned spacings, a plant density of 40-50k plants per ha will produce the optimum size flowers and stems (Schoellhorn et al., 2003). Sunflower growers should decide upon the optimum spacing after considering the local market demand for the grade of stems and flowers.

An experiment was conducted by Wien (2008) in which he grew two cultivars of sunflower, ‘Pro Cut Orange’ and ‘Sunrich Orange’. Wien (2008) planted at spacings of 23 × 23 cm and 30 × 30 cm resulting in marketable sized flowers and stems. There are also drawbacks of sowing seeds in high densities.

This could result in more chances of disease, less photosynthesis, thinner stems and smaller flowers with small disk size (Armitage & Laushman, 2003). The purpose of this experiment is to evaluate the influence of plant spacing on sunflower stem length, stem diameter, flower diameter, disk diameter, days to harvest and marketable stems.

Material Methods

Experimental Area

This experiment was conducted at Stephen F. Austin State University in Nacogdoches, Texas. The experimental area that was used for this experiment was raised beds in an open area between the SFASU Soccer Field and La Nana Creek. The dimensions of the raised beds were 365 × 121 × 61 cm. Soil analysis was performed to check the amount of nutrients present in the raised beds (Table 2.1). The pH for these raised beds was 7.67 which was within the range of 5.7 to 8.0 suitable for sunflower growth (Putnam et al., 1990). Treatments consisted of four different spacings 30 × 30 cm, 23 × 23 cm, 15 × 15 cm and 8 × 15 cm. Seeds were directly sown in the raised beds on 28 July 2017. Two seeds at each location were sown and thinned to 1 plant. Thinning and transplanting were done on 8 August 2017. The cultivars that were sown in the raised beds were 'Superior Gold', 'Pro Cut Gold', and 'Sunrich Lemon' (Table 2.2). Each bed had all four spacing treatments. The number of plants per row was 4, 5, 7 and 13 for the 30 × 30, 23 × 23, 15 × 15 and 8 × 15 cm spacing, respectively (n=64, n=80, n=112 and n=208).

Table 2.1. Nutrient levels present in the raised beds and their sufficiency ranges.

Nutrients	Raised bed (ppm)	Sufficiency range (ppm)
NO_3	1	100-199[z]
P	195.66	21-60[y]
K	84.64	120-300
Ca	6260.63	460-749
Mg	126.04	100-150
S	25.72	16-25
Fe	22.73	2.5-4.5
Mn	3.30	1-1.5
Zn	3.61	0.3-0.8
Cu	2.55	0.1-0.3

[z] Sufficiency range of a saturated media from Greenhouse Operation and Management (Nelson, 2012).
[y]Sufficiency ranges of soil from Stephen F. Austin State University Lab.

Table 2.2. Characteristics of three cultivars taken from Gloeckner Seed Catalog.

Cultivar	Comments	Photoperiodic Response[z]	Flower Color	Stems	Days to Harvest (d)	Plant Height (m)	Flower Diameter (cm)[y]
‘Superior Gold’	Fall and Shorter days	Facultative Short day	Golden yellow	Single	60	1.5-1.8	15-20
‘Pro Cut Gold’	Spring Summer, Fall	Day neutral	Golden orange	Single	60	1.2-1.8	10-15
‘Sunrich Lemon’	Spring, Summer, Fall	Facultative Short day	Lemon yellow	Single	55-70	0.9-1.5	10-15

[z]Data from Wien, 2014a; 2015
[y] Flower size from Gloeckner Seed 2016-2017 Catalog.

Beds were irrigated with drip irrigation. The plants were watered every other day for the duration of the trial. Beds were fertilized with Lone Star Super Lawn and Turf Builder, 15N-2.2P-8.3K (Texas Farm Products Co, Nacogdoches, TX), at a rate of 63 g per m^2 (Dole and Wilkins, 2005). Besides these macronutrients, this fertilizer included additional nutrients S (13.4%), B (0.02%), Cu (0.05%), Fe (1.0%), Mn (0.05%), Mo (0.0005%) and Zn (0.05%).

Sunflowers were harvested when the sunflower heads were fully developed and open. The measurements taken for each stem harvested were stem length measured from the base of the ground, stem diameter approximately 2.5 cm below the flower, flower diameter, disk diameter and harvest date. In this experiment, the minimum standard for cut flowers used was a stem length of 60 cm, stem diameter of 5 mm, flower diameter of 8 cm and disk diameter of 4 cm (Wien 2016, 2017; Sloan and Harkness, 2010).

The experimental design was a randomized complete block design with four replicates. The data was analyzed using SAS 9.2 (Cary, NC) via Two-Way ANOVA. Tukey's Studentized Range Test was used to find the significant differences between the means at a 5% probability level.

Results

Effect of plant spacing on ‘Superior Gold’, ‘Pro Cut Gold’, and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*).

For stem length there was a significant interaction between cultivars and treatments (Table 2.3). All three cultivars showed similar trends for stem length with stem length

Table 2.3. Effect of spacing on ‘Superior Gold’, ‘Pro Cut Gold’, and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) on stem length, stem diameter, flower diameter, disk diameter, days to harvest and marketable stems.

Cultivars	Spacings (cm)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Marketable stems (no.)
‘Superior Gold’	8×15	184.92a[z]	6.28b	13.04b	6.15a	60.13a	0.96ab
	15×15	173.49b	7.10a	13.66b	6.68a	58.41b	0.95ab
	23×23	166.55b	7.48a	13.37b	5.81a	58.66b	0.88b
	30×30	160.92b	8.87a	14.94a	6.50a	56.41c	0.98a
‘Pro Cut Gold’	8×15	129.63a	5.23c	9.36b	3.88b	49.28a	0.49b
	15×15	128.84a	4.95c	9.22b	3.85b	48.37ab	0.45b
	23×23	128.04a	6.99b	11.17a	4.84a	47.71bc	1.00a
	30×30	123.69a	7.91a	11.75a	4.86a	47.12c	0.95a
‘Sunrich Lemon’	8×15	119.76a	4.54a	7.92b	3.92a	60.84a	0.33a
	15×15	115.44a	4.71a	8.82a	4.11a	59.47b	0.44a
	23×23	105.83a	4.53a	8.54a	3.84a	56.17c	0.35a
	30×30	-	-	-	-	-	-
Significance	Cultivar	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Spacing	<0.0001	<0.0001	<0.0001	0.1930	<0.0001	<0.0001
	Interaction	0.0079	<0.0001	<0.0001	0.0366	0.0004	<0.0001

[z] Means within column for each cultivar followed by the same letter are not significantly different at the 5% probability level by Tukey’s Studentized Range Test.

increasing as the spacing decreased. However, only the ‘Superior Gold’ cultivar exhibited significant differences in stem length. There was no significant difference between spacing treatments for the cultivars ‘Pro Cut Gold’ and ‘Sunrich Lemon’. ‘Superior Gold’ being most vigorous produced longer stem length as compared to the ‘Pro Cut Gold’ and ‘Sunrich Lemon’. However, all three cultivars produced marketable stem lengths for all four spacing treatments.

For stem diameter, there was a significant interaction between cultivars and spacing treatments (Table 2.3). There was a general trend with stem diameter increasing as spacing increased. However, ‘Superior Gold’ and ‘Pro Cut Gold’ exhibited in significant differences in stem diameter producing marketable stems. Only ‘Sunrich Lemon’, the least vigorous cultivar, failed to produce marketable stem diameter at all four spacings.

There was a significant interaction between cultivars and spacing treatments for flower diameter (Table 2.3). All three cultivars showed a similar trend for flower diameter, with flower diameter increasing as spacing increased for all three cultivars. ‘Superior Gold’ and ‘Pro Cut Gold’ produced marketable flower diameters for all four spacing treatments whereas ‘Sunrich Lemon’, the least vigorous cultivar, failed to produce marketable flower diameter at the 8 × 15 cm spacing.

Although for disk diameter there was a significant interaction between the cultivar and spacing treatments there was no clear trend in the data related to spacing. Disk diameter increased with increasing vigour of the sunflowers with ‘Superior Gold’ producing the largest disk diameter followed by ‘Pro Cut Gold’ and ‘Sunrich Lemon’ (Table 2.3). ‘Pro Cut Gold’ produced marketable disk diameter at the 23 × 23 and 30 × 30 spacings, while ‘Sunrich Lemon’ produced marketable stems at the 15 × 15 spacing only.

There was a significant interaction between cultivars and spacing treatments for days to harvest (Table 2.3). As spacing decreased, the days to harvest increased for all three cultivars leading to a significant cultivar by spacing interaction.

There was a significant interaction for the number of marketable stems between the cultivars and spacing treatments (Table 2.3). Only ‘Pro Cut Gold’ exhibited a trend for the number of marketable flowers with the number of flowers declining as spacing declined. Although there was a decline in the number of marketable flowers for the 8 × 15 and 15 × 15 spacings, these spacings would have produced 41 and 20 flowers, respectively. The maximum number of marketable flowers at the 23 × 23 and 30 × 30 spacing would be 17 and 11 flowers, respectively.

Discussion

Marketability of the sunflower is determined by parameters such as stem length, stem diameter, flower diameter and disk diameter. In this experiment stem length increased as spacing decreased for only the ‘Superior Gold’ cultivar used in this experiment, which was not observed in previous research (Burnett, 2017; Sloan et al., 2004; Wien, 2012a). Stem diameter, flower diameter and disk diameter declined as spacing decreased (Table 2.3). This observation is consistent with previous spacing research on sunflowers (Burnett 2017; Sloan et al., 2004; Wien 2012a). In this experiment the days to harvest increased as sunflower spacing decreased for all three cultivars. Burnett (2017) did not observe a similar trend of spacing affecting days to harvest. When evaluating the number of marketable stems based on market standards of stem length (≥ 60cm), stem diameter (≥ 5mm), flower diameter (≥ 8cm) and disk diameter (≥ 4cm), there was a significant reduction in the number of marketable stems as spacing decreased for all three cultivars combined (Table 2.3). Independently ‘Superior Gold’ averaged 0.94 marketable stems for all four spacings. ‘Pro Cut Gold’ at the 8 × 15 and 15 × 15 cm spacings averaged 0.47 marketable stems compared to an average of 0.98 marketable stems at the 23 × 23 cm and 30 × 30 cm spacings.

Although the number of marketable stems on average declined, as spacing decreased the actual number of marketable stems per m^2 was substantially higher, for example 30 × 30 cm spacing at 1.0 = 11 stems but 15 × 15 cm spacing at 0.50 = 22 stems for the same area. The maximum number of stems produced by the 8 × 15 cm spacing = 83 stems per m^2, 15 × 15 cm = 44 stems per m^2, 23 × 23 cm = 17 stems per m^2, and 30 × 30 cm = 11 stems per m^2. Producing sunflowers with adequate stem length, when growing single stem sunflower cultivars is not a limiting factor even under high density plantings (Burnett, 2017; Sloan et al., 2004; Wien, 2012a). Sunflowers, like many crops, respond to high density planting by increasing stem length. This observation is consistent with previous research on sunflowers explains that under dense planting the amount of red-light/far red-light (R/FR) ratio reaching the stem of the crop is reduced thus increasing the stem length (Ballare et al., 1987; Libenson et al., 2002). Ballare et al. (1987, 1988) explains that the R/FR light ratio signal is established earlier in densely populated crops as compared to less densely populated crops. These signals reach the stem of the seedling where it is perceived by phytochrome and promotes stem elongation. All the spacing treatments produced marketable stem length similar to previous research (Burnett, 2017; Sloan et al., 2004; Wien, 2012a). Similar to previous spacing research trials (Burnett, 2017; Wien, 2012a), this spacing experiment produced smaller stem diameters and flower diameters. Similar to Burnett (2017) with 15 ×15, 23 ×23, and 30 × 30 cm spacing treatments, this spacing experiment produced marketable flower diameter for all the spacing treatments.

Vigour of individual cultivars ranked from most vigorous to least was ‘Superior Gold’, ‘Pro Cut Gold’ and ‘Sunrich Lemon’ (Table 2.2). Similarly to Sloan and Harkness (2006), ‘Superior Gold’, being more vigorous, produced longer stem length, larger stem, flower and disk diameters for all the spacing treatments. ‘Pro Cut Gold’ a moderately vigorous cultivar, produced longer stem length, larger stem, flower and disk diameter as compared to ‘Sunrich Lemon’. Similar to Sloan and Harkness (2006), close plant spacing should be considered for vigorous cultivar like ‘Superior Gold’ to reduce stem diameter, flower diameter, and disk diameter whereas less vigorous cultivar such as ‘Sunrich Lemon’ had smaller stem diameters that did not meet marketable standards.

There was a consistent trend for days to harvest; as the spacing increased days to harvest decreased for this experiment. The spacing trial conducted by Burnett (2017) found no significant difference in days to harvest with 15 ×15, 23 × 23, and 30 × 30 cm spacing treatments.

Conclusion

'Superior Gold' sunflowers, being the most vigorous, produced marketable stem length, stem diameter, flower diameter and disk diameter for all four spacing treatments (Table 2.3). 'Pro Cut Gold', a moderate vigorous sunflower, produced marketable disk diameters and stem diameters for the 30 × 30 and 23 × 23 cm spacing treatments (Table 2.3). 'Sunrich Lemon', being the least vigorous, failed to produce marketable stem diameters and disk diameters for all spacings (Table 2.3).

The results from this experiment indicate that vigorous sunflower cultivars produce marketable sunflowers in high density plantings in the fall. However, as vigour of the sunflower cultivar declines the density of planting should be increased to insure production of marketable sunflowers. Further research is needed to evaluate the influence of sunflower vigour and density of sunflowers grown in the spring and summer to determine if similar results occur.

Summary

Results of the two experiments conducted at Stephen F. Austin State University on various cultivars of sunflowers in East Texas demonstrated the production of sunflower can be increased by pinching in late spring. The production of *Helianthus annuus* decreased when pinching was done in late summer. Trial 1A conducted in late spring produced marketable stem lengths, stem diameters, flower diameters and disk diameters. Trial 1B conducted in late summer produced marketable stem lengths and flower diameters but some of the cultivars failed to produce marketable stem diameters and disk diameters.

Pinching was successful in East Texas during the late spring; however, the success of pinching decreases in summer. Pinching was not as successful in summer in Nacogdoches, Texas as it was in Ithaca, New York. Mild summer temperatures of New York likely allowed sunflowers to produce more marketable stems. In East Texas temperatures are higher as compared to the temperatures in New York. Day length during summer is also shorter as compared to New York. High temperature resulted in earlier initiation of flowering and as a result flowers produced smaller disk size as compared to the longer days (Blacquiere et al., 2002). For the growers in East Texas pinching is a successful method for increasing the production of sunflowers in spring with vigorous sunflower cultivar.

Growers should not practice pinching in late summer because it would result in unmarketable sunflower stem diameter and disk diameter.

The second experiment conducted in the summer to evaluate the effect of spacing on cultivars of sunflowers. ‘Superior Gold’ and ‘Pro Cut Gold’ produced marketable stems. However, ‘Sunrich Lemon’ failed to produce marketable stem diameters and disk diameters for some spacing treatments. High plant density was successful for ‘Superior Gold’ and ‘Pro Cut Gold’ but high density planting was not successful for the cultivar ‘Sunrich Lemon’ during late summer in East Texas.

Results from this research indicates that pinching increases the number of marketable stems for ‘Superior Gold’, ‘Pro Cut Gold’, ‘Sun Bright Supreme’, and ‘Sunrich Lemon’ in East Texas during late spring.

Results from spacing experiment indicate that decreased spacing is beneficial in increasing the number of marketable stems for ‘Superior Gold’ and ‘Pro Cut Gold’ whereas decreased spacing is not recommended for ‘Sunrich Lemon’.

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