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Economic Analysis of Sunflower (Helianthus annuus) Spacing in East Texas

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By

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IN EAST TEXAS

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Abstract

Two experiments were conducted on spacing of *Helianthus annuus* in East Texas to determine the spacing treatment that produces the greatest revenue per m^2. The experiments had four spacing treatments of 8 × 15 cm, 15 × 15 cm, 23 × 23 cm, and 30 × 30 cm. Three different cultivars were used in each experiment to determine if there was an interaction between spacing and cultivars. In both experiments, the stem height, stem diameter, flower diameter, and disk diameter increased as spacing increased. Also, as spacing increased, the days-to-harvest decreased. The 8 × 15 cm spacing produced the largest percentage of unmarketable and smaller size flowers while the 30 × 30 cm spacing produced the fewest unmarketable flowers. The net revenue declined substantially with increased spacing. Analysis of these two experiments concluded the most profitable spacing of specialty cut sunflowers grown in East Texas is 8 × 15 cm. East Texas growers should consider the quality and quantity of desired crop to determine the proper spacing of specialty cut sunflowers.

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Introduction

Specialty cut flowers have become an important segment in the United States' cut flower industry. Specialty cut flowers are considered any cut flower other than carnations, chrysanthemums, and roses. The top specialty cut flowers are gerbera, gladiolus, and tulips. In 2002, the production of carnations, chrysanthemums, and roses yielded $78 million, which only made up 15% of the market, while specialty cut flowers produced $443 million (Bachmann, 2006). There are over 100 species of specialty cut flowers grown in the United States. These species include annuals, perennials, shrubs, grasses, and native plants (Bergmann, 2018). Specialty cut sunflowers have been bred for architecture, performance, duration of flowering, and flower size (Cvejic et al., 2017).

Spacing of sunflowers is important for producing a successful crop because the size and quality of sunflowers can be influenced by the spacing of plants. The grower must decide what market they are growing for to determine the optimal planting density (Mladenović et al., 2020). Planting more densely can increase the yield and plant height possibly because of more light interception when the plant is in a vegetative stage (Gubbels and Dedio, 1988).

To examine the effects of spacing on specialty cut sunflowers, this research evaluated four different spacings and four cultivars. The four spacing treatments were 8 × 15 cm, 15 × 15 cm, 23 × 23 cm, and 30 × 30 cm. The four different cultivars used were ‘Superior Gold,’ ‘ProCut Gold,’ ‘ProCut Gold Lite DMR,’ and ‘Sunrich Lemon.’ In experiment 2, ‘ProCut Gold’ used in expt. 2A was replaced with ‘ProCut Gold Lite DMR’ in expt. 2B because ‘ProCut Gold’ was not available. Different cultivars were used to determine if there was an interaction between spacing and cultivars. Measurements recorded were stem length, stem diameter (approximately 2.5 cm below the base of the flower), flower diameter, disk diameter, and harvest date. The data collected was used to determine flower marketability and net revenue per m^2.

Objectives

There are two main objectives of this research:

1. Determine how sunflower spacing and cultivar vigor affect the growth and development of sunflowers
2. Provide an economic analysis of the effects of spacing and cultivar vigor on net revenue for East Texas specialty cut sunflowers

Literature Review

Sunflower History

Sunflowers (*Helianthus annuus)* are grown for many commercial purposes including oil production, seed for human consumption, bird seed, and specialty cut flowers (Schoellhorn et al., 2003). Sunflowers are used for human consumption because they have anticholesterol properties and protein contents of 13–20 percent (Brar et al., 2016). They are one of the native crops grown in the United States. Native Americans domesticated sunflowers for use as food and oil. There is significant production of sunflowers on every continent except Antarctica. From 2014–2015 there was an estimated 23.2 million hectares (ha) of sunflowers grown around the world. There are 53 species, which include 39 perennials and 14 annuals. The Institute of Field and Vegetable Crops has bred 100 hybrids and 70 joint hybrids using genes from wild species of sunflowers (Atlagic and Terzic, 2016). Research has been conducted on the wild species of sunflowers for use in breeding of disease resistance, abiotic salt tolerance, and resistance to sulfonylurea herbicides. This research has helped produce plants that can withstand environmental challenges such as drought and salinity by incorporating traits from wild species (Seiler et al., 2017).

The agronomic and wild sunflowers are not suitable for cut flower production. Bedding and cut flower cultivars of sunflowers have been introduced to the market (Schoellhorn et al., 2003). These cultivars were bred for architecture, performance, duration of flowering, and flower size (Cvejic et al., 2017). This breeding required six generations of self-pollination to ensure stable genetics in the genotype. The selected ray colors were yellow, lemon, and orange. The disk colors were yellow, orange, and purple (Mladenović et al., 2020). Cut sunflower stems should be between 60–90 cm in length, the flower should be 8–15 cm in diameter, and the stem diameter should be 0.5–1.5 cm. These flowers should also have a strong stem that is not thick and a long vase life (Cvejic et al., 2017; Sloan and Harkness, 2006). Florists have a variety of sunflower sizes available to them. The size of the flower needed is based on the arrangement and personal preference of the florist. Large sunflowers are generally not used in standard arrangements (Sloan and Harkness, 2006).

Cut flowers are the main export in the floriculture industry. Growers in the United States, Europe, and Japan focus on specialty products such as specialty cut flowers and seasonal products to compete globally (Rabobank, 2015). Although specialty cut flowers are more costly to produce and do not tolerate long-distance shipping, growers can earn between $10,000 to $12,000 per hectare (Garfinkel and Panter, 2014).

Economic Impact

Cut flowers are grown for many occasions and can be sold in local direct retail markets or local wholesale markets. Small sunflower growers can do well selling at a local farmers' market where fresh produce is sold (Stevens et al., 1993). In 2009, annual cut flower production was worth $400 million. The majority of the market is imports from the Netherlands, Columbia, and Kenya (Short et al., 2017). The 2021 wholesale cost for five long sunflower stems is on average $7.50. A bunch of 10 long sunflower stems averages $12.50, whereas a bunch of 10 long specialty miniature sunflowers is $9.50 (USDA, 2021). According to the USDA, the average wholesale price for a single sunflower stem is $1.10, and a bunch of 5 stems $7.67. In 2020, wholesale prices increased at the beginning of July with a single stem costing $1.13 (USDA, 2020). The standard markup for cut flowers is three times the price of wholesale. The retail price for a standard sunflower is $4.50 a stem, and specialty cultivars are $6.00 a stem (Short et al., 2017).

According to the USDA report on operations, with more than $100,000 in sales there were 14 million sunflower stems sold at wholesale in 2018. In Texas there are three producers with more than $100,000 in sales and 93 producers across the United States with more than $100,000 in sales (USDA, 2019).

Growing Conditions

Sunflowers are grown in full sun and are drought tolerant. Sunflowers grow well in a pH range of 6.5–7.5 and temperatures ranging from 22–30°C (Schoellhorn et al., 2003). Research conducted on the influence of pH on sunflower growth has shown a negative impact on growth when sunflowers are grown in soils with low pH. The number of flowers harvested was reduced when grown in low pH soil. Plant mortality increased by 10% when the soil pH was 4.7 or less. When the soil pH was 4.0 or less, plant mortality was 26%. It was also found that plant height increases with increasing pH until it plateaus at a pH of approximately 4.9 (Sutradhar et al., 2014). Research conducted on nitrogen application showed the increased nitrogen fertilization resulted in increased stem lengths and decreased days-to-harvest (Ahmad et al., 2012). Potassium is important for cut flower stem strength. It is recommended to apply liquid fertilizer 20-20-20 at a rate of 100-200 mg/L 5–15 cm below the seed to improve potassium levels (Schoellhorn et al., 2003).

Research conducted on the effects of temperature on sunflowers showed temperature could affect leaf mass and leaf area. Increased temperature from 23°C days and 19°C nights to 33°C days and 29°C nights decreased leaf mass and area. The increased temperature decreased the photosynthetic and transpiration rate compared to control plants. Plants grown at higher temperatures also had significantly lower chlorophyll content compared to control plants (Haba et al., 2020).

Spacing

Sunflowers should be spaced 15–30 cm apart with each row being 45–90 cm apart. When growing for cut flowers, plants can be spaced 15 × 15 cm (Schoellhorn et al., 2003). Research has been conducted on spacing of sunflowers with 45 and 90 cm rows. The 45 cm spacing produced 14.5% more yield than the 90 cm spacing. When oil content was measured, the 45 cm spacing also produced more than the 90 cm spacing. This trend of increasing yield in the 45 cm spacing was seen in early maturing hybrids and not in late-maturing hybrids. The increase in yield in narrower spacing is hypothesized to be because of greater light interception in the early stages of growth. This research also found that plant height was reduced by 9 cm in the 90 cm spacing compared to the 45 cm spacing (Gubbels and Dedio, 1988). An experiment conducted at Cornell University showed sunflowers spaced at 15 × 15 cm produced flower diameters of 4.8 cm, stem lengths of 144 cm, and produced 4139 flowers per 304 m^2. Flowers spaced at 30 × 30 cm produced flower diameters of 6.7 cm, stem lengths of 138 cm, and 1093 flowers per 304 m^2 (Wien, 2012). This research showed an increase in spacing produced an increased flower size but reduced the number of flowers that can be produced per m^2. The quality and yield of cut sunflowers can be manipulated based on spacing. Optimal planting density is based on the quality and quantity of sunflowers the grower is trying to achieve (Mladenović et al., 2020).

Flowering

The sunflower’s flower is formed within three weeks of germination (Wien, 2014). Different cultivars respond to daylength and time of flowering (Wien, 2014). The transition from the vegetative stage to reproductive (flowering) is triggered by environmental factors such as photoperiod or temperature changes (Saupe, 2009). If plants are exposed to short days during early development, they will flower earlier. Exposing plants to long days will keep the plant in its vegetative stage during early development to produce marketable flowers (Wien, 2014). In an experiment conducted in New York, ‘ProCut Gold’ showed no significant difference between short day and long day exposure in the first three weeks and was classified as having a day-neutral photoperiod (Wien, 2014). ‘Sunrich Lemon’ and ‘Superior Gold’ cultivars were not tested for flowering response in the experiment.

Producing marketable flowers is also important when producing specialty cut sunflowers. In a study conducted at Cornell University, minimum standards for disk diameters were set based on the USDA cut flower terminal market price list. If the disk diameter is less than 3.8 cm, the flower is non-marketable. Flowers with disk diameters between 3.8–6 cm were worth $0.85, disk diameters of 6–8 cm were worth $1.00, and disk diameters over 8 cm were worth $1.50 (Wien, 2016).

Sunlight Effect

Sunlight is an important factor in plant growth. The plant uses pigments within the leaves to absorb the wavelengths of light emitted by the sun. There are twp types of chlorophyll the plant uses to absorb light including chlorophyll a and chlorophyll b. Other pigments the plant can use include carotenoids, fucoxanthin, and phycobilins. Sunflowers use chlorophyll a, chlorophyll b, and carotenoids to absorb light. These pigments tend to absorb only red and blue wavelengths giving the sunflower leaves their green color (Nishio, 2000). Since the plants are not able to move to absorb the correct amount of light needed to grow, they have to be planted at the correct spacing to allow light into the leaf canopy. Shaded plants receive reduced photosynthetic active radiation, which forces the plant to develop a shade avoidance system that induces linear growth toward the light source (Nozue et al., 2015). The increased stem growth has been shown to reduce yields because nutrients and water were utilized in stem growth instead of flower production (Libenson et al., 2002). Shaded plants can have decreased flowering time and suppressed growth in other parts of the plant (Nozue et al., 2015).

Germination

Seed germination is an important step in the life cycle of plants. Without successful germination an established field cannot be grown. Seeds are vulnerable to many stresses including water, temperature, light, and salts in the soil. This stress can lead to injury or death of the plant before or after germination. Salts in the soil can be the most crucial factor in seed germination in arid and semiarid soils. High salinity levels in soil can prevent seeds from taking in water by creating an external osmotic potential. Research has shown that planting seeds at optimal temperatures can reduce the effect of salinity in the soil (Luan et al., 2014).

Another influence on seed germination is the size of the seed. Seeds are different sizes at different maturity stages because of the amount of reserves they have stored inside of them. To determine the viability of the seed, it is best to measure the size of the embryotic tissue and the size of the reserve tissue within the seed. This measurement can be done using X-ray images. These images can also show if there are empty seeds or malformations within the seed. Research conducted using this X-ray image method for sunflower seeds showed that the embryo filled more than 60% of the seed area for all analyzed seeds. The research also showed that larger embryos do not show a higher germination rate (Rocha et al., 2014).

Irrigation

Sunflowers are grown around the world as a rain-irrigated crop. Sunflowers respond positively to irrigation where water supply is limited (Kadasiddappa et al., 2017). The amount of irrigation needed is based on the crop and weather. An average of 0.38 cm of water is used per day by actively growing sunflowers. When mature sunflowers are growing under temperatures of 35°C, they may use 0.76 cm of water per day (Stevens et al., 1993). When water is limited, the production can be measured in terms of yield per unit of land or yield per unit of water.

Research has shown an increase in irrigation increases plant height. For example, plants irrigated every 10 days were significantly taller than plants irrigated every 18 days. Sunflowers are sensitive to water stress in the flowering and seed maturity stages of growth. Drip irrigation has been shown to create the most favorable soil conditions with adequate moisture and low salinity levels at the root zone (Kadasiddappa et al., 2017). Overhead irrigation is not ideal because it can cause damage to the plants. Petal damage can occur and soil splashing onto the leaves promotes the spread of disease (Stevens et al., 1993). Research has shown planting seeds in raised beds produced higher yields and reduced the amount of irrigation water needed (Brar et al., 2016). The amount of moisture in the soil impacts the nutrients the plant can uptake. With increased irrigation, nitrogen, phosphorus, potassium, and sulfur uptake was increased. This increased uptake and nutrient concentration led to increased economic yields (Kadasiddappa et al., 2017).

Insects, Pests, and Diseases

Controlling insects, pests, and diseases in sunflowers is important to producing a successful crop. Insects can feed on the stem and head tissue of the sunflower and cause problems with nutrient flow to the plant. These insects can also weaken the structure of the plant. External damage to the plant will reduce the value and marketability of the crop. The primary insects that cause damage to sunflowers include sunflower beetle (*Zygogramma exclamationis*), sunflower bud moth (*Suleima helianthana*), sunflower maggot (*Strauzia longipennis*), caterpillar (*Rhopalocera sp.*), and grasshopper (*Schistocerca americana*) (Stevens et al., 1993). Diseases that affect sunflowers can also negatively impact the value of the crop. There are more than 90 diseases that affect sunflowers worldwide, with many of them being fungi (Mukhtar, 2009). Common sunflower diseases include Sclerotinia wilt (*Sclerotinia sclerotiorum),* Downy mildew (*Plasmopora halstedii*), Phoma (*Phoma sp.*), Rust (*Puccinia helianthin*), and Rhizopus head rot (*Rhizopus stolonifera)*. These insects and diseases need to be controlled early to ensure the success of the crop (Stevens et al.,1993). The most economically effective control of sunflower diseases and pests is planting resistant or tolerant cultivars. It is also important to have a crop rotation of at least four years between crops (Kandel et al., 2018).

Justification

This research will examine the most effective spacing and cultivar of specialty cut sunflowers and produce a spacing guide for East Texas growers to produce sunflowers of the desired size. The size of sunflowers can be manipulated based on how densely they are grown. The current spacing recommendation for specialty cut sunflowers is 15 × 15 cm (Schoellhorn et al., 2003). This research will provide recommendations for adjusting spacing to manipulate flower size for growers in East Texas.

EXPERIMENT: 1A, 1B, 2A, and 2B: Effect of spacing and cultivar vigor on sunflowers (*Helianthus annuus*).

Introduction

Spacing of sunflowers affects the growth and development of sunflowers. The relationship between spacing and flower size is important for growers to determine to produce marketable flowers (Mladenović et al., 2020). Spacing determines the amount of competition for sunlight, nutrients, and water between plants. Competition for sunlight can negatively impact flower size because the plant will avoid shade by growing linearly. If the plant uses nutrients and water to grow linearly, fewer resources will be available for flower production (Nozue et al., 2015). Competition for water is also a factor when determining proper spacing. Research has shown that sunflowers respond positively to regular irrigation. The water content in the soil also determines the amount of nutrients available for the plant to take up (Kadasiddappa et al., 2017).

The USDA standards classify sunflowers based on their disk diameter. A disk diameter less than 3.8 cm is non-marketable. Flowers with disk diameters between 3.8–6 cm (small) are worth $0.85, disk diameters of 6–8 cm (medium) are worth $1.00, and disk diameters over 8 cm (large) are worth $1.50 (Wien, 2016). Florists buy flowers based on preference and design. Very large sunflowers are usually not preferred by florists (Sloan and Harkness, 2006). Flowers need to return a profit and be a desirable size for florists and consumers. The current spacing recommendation for growing desirable sunflowers is 15 × 15 cm (Schoellhorn et al., 2003). Determining proper growing space is essential to produce sunflowers that are economically viable.

Materials and Methods

Experiments (1A,1B, 2A, and 2B) were conducted at Stephen F. Austin State University in Nacogdoches, Texas. The experimental area was an open field between the SFASU Soccer Field and La Nana Creek. The raised beds were 121 × 365 × 61 cm in dimensions. The beds were prepared for planting on 12 April 2018 (Expt. 1A), 29 June 2018 (Expt. 1B), 6 May 2020 (Expt. 2A), and 16 July 2020 (Expt. 2B). This experiment had four spacing treatments of 8 × 15 cm, 15 × 15 cm, 23 × 23 cm, and 30 × 30 cm. Each experiment contained 3 cultivars, expts. 1A, 1B, and 2A: ‘Superior Gold,’ ‘ProCut Gold,’ and ‘Sunrich Lemon,’ expt. 2B: ‘Superior Gold,’ ‘ProCut Gold Lite DMR,’ and ‘Sunrich Lemon’ (Table 1.1). ‘ProCut Gold’ used in expt. 2A was replaced with ‘ProCut Gold Lite DMR’ in expt. 2B because ‘ProCut Gold’ was not available. Two seeds were directly sown at each location and then thinned to one plant. There were 12 raised beds planted for each experiment with 4 replications of each spacing. Beds were fertilized with Lone Star Super Lawn and Turf Builder 15N-5P-10K (Texas Farm Products Co, Nacogdoches, TX) at a rate of 5.6 g N per m^2. The fertilizer had additional nutrients including S (13.4%), B (0.02%), Cu (0.05%), Fe (1.0%), Mn (0.05%), Mo (0.0005%), and Zn (0.05%). Raised beds were irrigated with drip irrigation every other day for the duration of the experiment except for the days it rained.

Table 1.1 Characteristics of four sunflower cultivars taken from Gloeckner Seed Catalog 2016-2017 and Ball Seed Catalog 2021-2022

Cultivar	Flower Color	Stems	Days-to-Harvest	Plant Height (cm)	Flower Diameter (cm)
'Superior Gold'[z]	Golden Yellow	Single	60–70	152–182	15–20
'ProCut Gold'[y]	Gold	Single	55	152–183	10–13
'ProCut Gold Lite DMR'[y]	Gold	Single	50–55	152–183	10–13
'Sunrich Lemon'[z]	Bright Yellow	Single	60–65	91–185	13–15

[z] Data from Gloeckner Seed Catalog 2016-2017

[y] Data from Ball Seed Catalog 2021-2022

Sunflowers were harvested when the rays were fully developed and open. Stem length was measured from the ground to the base of the flower. Additional measurements recorded were stem diameter (approximately 2.5 cm below the base of the flower), flower diameter, disk diameter, and harvest date. The minimum standards set in this experiment were a stem length ≥60 cm, stem diameter ≥5 mm, flower diameter ≥8 cm, and disk diameter ≥3.8 cm (Sloan and Harkness, 2010; Wien, 2016). Flowers were evaluated based on disk diameter to determine their dollar value per m^2, as per USDA standards. Disk diameters less than 3.8 cm were non-marketable. Flowers with disk diameters between 3.8–6 cm (small) were worth $0.85, disk diameters of 6–8 cm (medium) were worth

$1.00, and disk diameters over 8 cm (large) were worth $1.50 (Wien, 2016). Net revenue was determined by the possible number of flowers in a m^2 and the percentage of marketable flowers in each size category.

The experimental design was a randomized complete block design with four replications. The data were analyzed using SAS 9.2 with Two-Way ANOVA. A Tukey's Studentized Range Test was used to test significant differences between means with a probability level of 5%. Flower size distribution and net revenue per m^2 data were categorized based on disk diameter. Flower size distribution and net revenue per m^2 were analyzed with a frequency test using SAS 9.2.

Results

In expts. 1A, 1B, 2A, and 2B there was a significant interaction between cultivars and spacing treatments for stem length, stem diameter, flower diameter, and disk diameter (Tables 1.2, 1.3, 1.4, and 1.5). In expts. 1A, 2A, and 2B there was a significant interaction between cultivars and spacing treatments for days-to-harvest. However, in expt. 1B there was not a significant interaction between cultivars and spacing treatments for days-to-harvest. Although there was a significant cultivar and spacing interaction, the interaction will not be focused on because cultivars were selected based on known differences in cultivar vigor.

Stem Length

In expt. 1A, 'ProCut Gold' sunflowers showed a trend of increasing stem length with increasing spacing treatment (Table 1.2). There was no clear trend for cultivars 'Sunrich Lemon' and 'Superior Gold.' However, cultivar 'Superior Gold' had a significantly shorter stem length for the 8 × 15 cm spacing compared to the other spacings. Stem length was significantly taller for 'Superior Gold' (218 cm) compared to 'ProCut Gold' (140 cm) and 'Sunrich Lemon' (136 cm). However, all three cultivars yielded marketable stem lengths (≥60 cm) for all four spacing treatments.

In expt. 1B, there was no general trend between spacing treatments and cultivars for stem length (Table 1.3). There were no significant differences between spacing treatments for all three sunflower cultivars. Stem length was significantly taller for the ‘Superior Gold’ cultivar (214 cm) compared to ‘ProCut Gold’ (147 cm) and ‘Sunrich Lemon’ (135 cm). However, all three cultivars yielded marketable stem lengths (≥60 cm) for all four spacing treatments.

In expt. 2A, cultivars ‘Superior Gold’ and ‘Sunrich Lemon’ showed a general trend of stem length increasing as spacing increased (Table 1.4). However, only the 8 × 15 cm spacing was significantly shorter than the other spacings for the ‘Superior Gold’ and ‘Sunrich Lemon’ cultivars. The 8 × 15 cm (156 cm) spacing treatment was significantly shorter than the 15 × 15 (173 cm), 23 × 23 (177 cm), and 30 × 30 cm (178 cm) spacings, respectively. Stem length was significantly taller for the ‘Superior Gold’ cultivar (233 cm) compared to ‘ProCut Gold’ (150 cm) and ‘Sunrich Lemon’ (150 cm). However, all three cultivars yielded marketable stem lengths (≥60 cm) for all four spacing treatments.

In expt. 2B, there was no significant difference between spacing treatments for stem length (Table 1.5). The ‘Superior Gold’ cultivar showed a trend of increasing stem length with increasing spacing treatment. The most vigorous cultivar ‘Superior Gold’ produced the longest stem length (174 cm) compared to ‘ProCut Gold Lite DMR’ (119.8 cm) and ‘Sunrich Lemon’ (116.2

cm). However, all three cultivars yielded marketable stem lengths (≥60 cm) for all four spacing treatments.

Stem Diameter

In expt. 1A, all three cultivars had a general trend of increasing stem diameter with increasing spacing treatments (Table 1.2). Cultivars ‘Sunrich Lemon’ and ‘Superior Gold’ showed that the stem diameters for the 23 × 23 and 30 × 30 cm were significantly larger than other spacing treatments. There was a significant difference between all four spacings with the 30 × 30 cm (16.5 mm) spacing having the largest stem diameter followed by the 23 × 23 (15.4 mm), 15 × 15 (13.5 mm), and 8 × 15 cm (11.9 mm) spacings, respectively. Similarly, there was a significant decrease between cultivars with ‘Superior Gold’ having the largest stem diameter (16.8 mm), followed by ‘ProCut Gold’ (13.7 mm) and ‘Sunrich Lemon’ (12.4 mm). The stem diameter decreased as the vigor of each cultivar decreased. All three cultivars and four spacings produced marketable stem diameters of ≥ 5 mm.

In expt. 1B, both the ‘Superior Gold’ and ‘ProCut Gold’ cultivars had a significant increase in stem diameter as spacing increased (Table 1.3). All three cultivars showed a general trend of increasing stem diameter with increasing spacing treatment, but there was no significant difference for the ‘Sunrich Lemon’ sunflowers. There was a significant difference in stem diameter between cultivars with ‘Superior Gold’ having the largest stem diameter (16.7 mm) followed by ‘ProCut Gold’ (14.4 mm) and ‘Sunrich Lemon’ (11.5 mm). All three cultivars produced marketable stem diameters of ≥ 5 mm.

In expt. 2A, all three cultivars showed a similar trend of stem diameter increasing as spacing increased (Table 1.4). There was a significant difference between all four spacings with the 30 × 30 cm (9.8 mm) spacing having the largest stem diameter followed by the 23 × 23 (8.6 mm), 15 × 15 (7.0 mm), and 8 × 15 cm (5.6 mm) spacings, respectively. Similarly, there was a significant difference in stem diameter between cultivars with ‘Superior Gold’ having the largest stem diameter (9.2 mm) followed by ‘ProCut Gold’ (7.2 mm) and ‘Sunrich Lemon’ (6.9 mm). However, all cultivars and spacing treatments yielded marketable stem diameters of ≥ 5 mm.

In expt. 2B, cultivars ‘Superior Gold’ and ‘ProCut Gold Lite DMR’ showed a general trend of increasing stem diameter with increasing spacing treatment (Table 1.5). There was a significant difference between all four spacings with the 30 × 30 cm (9.3 mm) spacing having the largest stem diameter followed by the 23 × 23 (8.2 mm), 15 × 15 (7.4 mm), and 8 × 15 cm (6.7 mm) spacings. There was no significant difference between the spacing treatments for cultivar ‘Sunrich Lemon’. Similarly, there was a significant difference in stem diameter between cultivars with ‘Superior Gold’ having the largest stem diameter (9.5 mm) followed by ‘ProCut Gold Lite DMR’ (7.8 mm) and ‘Sunrich Lemon’ (6.5 mm). All three cultivars yielded marketable stem diameters (≥ 5 mm) mm at all four spacing treatments.

Flower Diameter

In expt. 1A, all three cultivars showed a general trend of increasing flower diameter with increasing spacing treatment (Table 1.2). The ‘ProCut Gold’ cultivar had a significantly larger flower diameter at the 30 × 30 cm spacing. However, cultivars ‘Sunrich Lemon’ and ‘Superior Gold’ showed no significant difference between the 23 × 23 and 30 × 30 cm spacing treatments. There was a significant difference between all four spacings with the 30 × 30 cm (16.5 cm) spacing having the largest flower diameter followed by the 23 × 23 (15.4 cm), 15 × 15 (13.5 cm), and 8 × 15 cm (11.9 cm) spacings, respectively. Similarly, there was a significant difference between cultivars with ‘Superior Gold’ having the largest flower diameter (16.8 cm) followed by ‘ProCut Gold’ (13.7 cm), and ‘Sunrich Lemon’ (12.4 cm). The flower diameter decreased as the vigor of each cultivar decreased. All three cultivars produced marketable flower diameters (≥8 cm) at all four spacing treatments.

In expt. 1B, both the ‘Superior Gold’ and ‘ProCut Gold’ cultivars had a significant increase in flower diameter as spacing increased (Table 1.3). Cultivar ‘Sunrich Lemon’ did not show a general trend of increasing flower diameter with increasing spacing treatment. The 30 × 30 spacing treatment was significantly larger than the other spacings. There was a significant difference in flower diameter between cultivars with ‘Superior Gold’ having the largest flower diameter (16.6 cm), followed by ‘ProCut Gold’ (14.4 cm) and ‘Sunrich Lemon’ (11.6 cm). All three cultivars produced marketable flower diameters (≥8 cm) at all four spacings.

In expt. 2A, all three cultivars showed a similar significant trend with flower diameter increasing as spacing treatment increased (Table 1.4). All three cultivars had a significantly smaller flower diameter for the 8 × 15 cm spacing compared to the other spacings. The ‘Superior Gold’ cultivar had a significantly larger flower diameter (17.2 cm) compared to ‘ProCut Gold’ (14.0 cm), and ‘Sunrich Lemon’ (11.9 cm). All three cultivars produced marketable flower diameters of ≥8 cm.

In expt. 2B, cultivar ‘Superior Gold’ showed a general trend of increased flower diameter with increasing spacing treatment (Table 1.5). There was no significant difference between spacing treatments for cultivar ‘Sunrich Lemon’. There was a significant difference in flower diameter between cultivars with ‘Superior Gold’ having the largest flower diameter (15.1 cm) followed by ‘Sunrich Lemon’ (11.0 cm) and ‘ProCut Gold’ (10.9 cm). All three cultivars produced marketable flower diameters (≥8 cm) at all four spacing treatments.

Disk Diameter

In expt. 1A, all three cultivars showed a general trend of increasing disk diameter with increasing spacing treatment (Table 1.2). There was a significant difference between all four spacings with the 30 × 30 cm (7.9 cm) spacing having the largest disk diameter, followed by the 23 × 23 (7.2 cm), 15 × 15 (6.0 cm), and 8 × 15 cm (5.2 cm) spacings, respectively. The ‘Superior Gold’ cultivar had a significantly larger disk diameter (7.6 cm) compared to ‘Sunrich Lemon’ (6.1 cm) and ‘ProCut Gold’ (5.9 cm). All three cultivars produced a marketable disk diameter of ≥ 3.8 cm.

In expt. 1B, cultivars ‘Superior Gold’ and ‘ProCut Gold’ showed a general trend of increasing disk diameter with increasing spacing treatment (Table 1.3). Cultivar ‘Sunrich Lemon’ did not show a significant difference between any spacing treatment for disk diameter. The 30 × 30 spacing treatment had significantly larger disk diameter than the other spacings. There was a significant difference in disk diameter between cultivars, with ‘Superior Gold’ having the largest disk diameter (8.1 cm) followed by ‘ProCut Gold’ (6.4 cm) and ‘Sunrich Lemon’ (5.5 cm). All cultivars produced marketable flowers at all four spacing with disk diameters ≥ 3.8 cm.

In expt. 2A, all three cultivars showed a similar trend of increasing disk diameter as the spacing treatment increased (Table 1.4). Cultivars ‘ProCut Gold’ and ‘Sunrich Lemon’ showed significantly smaller disk diameters for the 8 × 15 and 15 × 15 cm spacings compared to the other spacings. The ‘Superior Gold’ cultivar had a significantly larger disk diameter (7.5 cm) compared to ‘ProCut Gold’ (5.9 cm), and ‘Sunrich Lemon’ (5.8 cm). All three cultivars produced marketable disk diameters of ≥ 3.8 cm.

In expt. 2B, cultivar ‘Superior Gold’ showed a general trend of increasing disk diameter with increasing spacing treatment (Table 1.5). There was no significant difference between spacing treatments for cultivar ‘Sunrich Lemon’. There was a significant difference in disk diameter between cultivars with ‘Superior Gold’ having the largest disk diameter (6.7 cm) followed by ‘ProCut Gold’ (5.3 cm) and ‘Sunrich Lemon’ (5.2 cm). All three cultivars produced marketable disk diameters of ≥ 3.8 cm.

Days-to-harvest

In expt. 1A, cultivars ‘Sunrich Lemon’ and ‘Superior Gold’ showed a general trend of increasing days-to-harvest with decreasing spacing treatment (Table 1.2). However, there was no significant difference in days-to-harvest for ‘ProCut Gold’ sunflowers. For ‘Superior Gold’ and ‘Sunrich Lemon’ sunflowers days-to-harvest increased by approximately two days for the 8 × 15 cm spacing treatment compared to the 30 × 30 cm spacing.

In expt. 1B, days-to-harvest did not show a significant difference between cultivars and spacing treatments (Table 1.3). All three cultivars did not show a significant difference between all four spacing treatments. There was no general trend between spacing and cultivars for days to harvest. The average days-to-harvest for ‘Superior Gold,’ ‘ProCut Gold’ and Sunrich Lemon’ were 55, 46, and 65 days, respectively.

In expt. 2A, all three cultivars showed a significant difference for days-to-harvest between the 8 × 15 cm spacing compared to the other spacings (Table 1.4). The 8 × 15 cm spacing increased days-to-harvest by approximately two days compared to the other spacings for the ‘Superior Gold’ and ‘Sunrich Lemon’ cultivars and by approximately one day for the ‘ProCut Gold’ cultivar.

In expt. 2B, ‘Sunrich Lemon’ showed a significant difference for days-to-harvest at the 15 × 15 cm spacing (Table 1.5). There was no trend related to increasing spacing related to days-to-harvest. There was a significant difference between cultivars with the ‘ProCut Gold’ cultivar having the least days-to-harvest followed by ‘Superior Gold’ and ‘Sunrich Lemon.’

Table 1.2. Effect of spacing on 'Superior Gold,' 'ProCut Gold,' and 'Sunrich Lemon' sunflowers (*Helianthus annuus*) on stem length, stem diameter, flower diameter, disk diameter, and days-to-harvest, Expt. 1A.

Cultivars	Spacings (cm)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk Diameter (cm)	Days-to-harvest (d)
'Superior Gold'	8 × 15	191.3b[z]	14.0c	14.0c	6.1b	72.3a
	15 × 15	227.1a	16.2b	16.2b	7.1b	71.0b
	23 × 23	226.9a	17.9a	17.8a	8.4a	69.9b
	30 × 30	227.4a	19.0a	19.0a	9.0a	69.6b
'ProCut Gold'	8 × 15	134.8a	11.1d	11.1d	4.5d	57.9a
	15 × 15	138.0a	12.5c	12.5c	5.2c	57.3a
	23 × 23	142.6a	14.5b	14.5b	6.4b	57.3a
	30 × 30	144.9a	16.9a	16.9a	7.7a	57.8a
'Sunrich Lemon'	8 × 15	130.8a	10.6b	10.6b	5.0b	71.8a
	15 × 15	139.1a	11.7b	11.7b	5.7b	70.2b
	23 × 23	138.8a	13.7a	13.7a	6.9a	70.1b
	30 × 30	135.2a	13.7a	13.7a	7.0a	70.0b
Significance	Cultivar	<.0001	<.0001	<.0001	<.0001	<.0001
	Spacing	<.0001	<.0001	<.0001	<.0001	<.0001
	Interaction	0.0103	0.0002	0.0002	0.0065	<.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.

Table 1.3. Effect of spacing on 'Superior Gold,' 'ProCut Gold,' and 'Sunrich Lemon' sunflowers (*Helianthus annuus*) on stem length, stem diameter, flower diameter, disk diameter, and days-to-harvest, Expt. 1B.

Cultivars	Spacings (cm)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk Diameter (cm)	Days-to-harvest (d)
'Superior Gold'	8 × 15	205.0a[z]	14.5c	14.6b	6.6c	54.5a
	15 × 15	219.0a	16.5b	16.3b	7.8b	55.1a
	23 × 23	211.8a	17.0a	17.0a	8.3b	55.5a
	30 × 30	220.3a	18.7a	18.7a	9.6a	54.9a
'ProCut Gold'	8 × 15	140.1a	12.7b	12.7c	5.3c	46.7a
	15 × 15	150.9a	13.5b	13.5b	5.8b	47.0a
	23 × 23	153.9a	14.8a	14.8b	6.6b	45.7a
	30 × 30	145.4a	16.7a	16.7a	7.9a	46.6a
'Sunrich Lemon'	8 × 15	138.8a	11.0a	11.0a	5.2a	67.6a
	15 × 15	139.6a	11.5a	11.5a	5.6a	60.3a
	23 × 23	126.7a	11.5a	11.5a	5.5a	65.8a
	30 × 30	135.8a	12.2a	12.6a	5.9a	65.0a
Significance	Cultivar	0.0061	<.0001	<.0001	<.0001	<.0001
	Spacing	<.0001	<.0001	<.0001	<.0001	0.2692
	Interaction	0.0012	0.0004	0.0035	<.0001	0.1116

[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.

Table 1.4. Effect of spacing on 'Superior Gold,' 'ProCut Gold,' and 'Sunrich Lemon' sunflowers (*Helianthus annuus*) on stem length, stem diameter, flower diameter, disk diameter, and days-to-harvest, Expt. 2A.

Cultivars	Spacings (cm)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk Diameter (cm)	Days-to-harvest (d)
'Superior Gold'	8 × 15	198.7b[z]	6.6c	13.8c	5.1c	66.3a
	15 × 15	229.7a	8.1b	16.1b	7.3b	64.1b
	23 × 23	234.0a	10.0b	17.3b	8.1b	63.3b
	30 × 30	233.2a	12.0a	21.7a	9.4a	64.6b
'ProCut Gold'	8 × 15	137.3a	5.1b	12.1b	4.9b	52.6a
	15 × 15	142.5a	6.6b	13.2a	5.4b	51.8b
	23 × 23	148.3a	7.9a	15.1a	6.3a	51.4b
	30 × 30	150.3a	9.2a	15.8a	7.0a	51.2b
'Sunrich Lemon'	8 × 15	133.0b	5.0c	9.3b	4.1c	69.3a
	15 × 15	147.1a	6.2b	11.6a	5.4b	67.5b
	23 × 23	147.3a	8.0a	13.2a	6.6a	67.5b
	30 × 30	150.2a	8.3a	13.8a	7.1a	67.0b
Significance	Cultivar	<.0001	<.0001	<.0001	<.0001	<.0001
	Spacing	<.0001	<.0001	<.0001	<.0001	<.0001
	Interaction	<.0001	<.0001	0.0060	0.0005	0.0035

[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.*

Table 1.5. Effect of spacing on 'Superior Gold,' 'ProCut Gold Lite DMR,' and 'Sunrich Lemon' sunflowers (*Helianthus annuus*) on stem length, stem diameter, flower diameter, disk diameter, and days-to-harvest, Expt. 2B.

Cultivars	Spacings (cm)	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk Diameter (cm)	Days-to-harvest (d)
'Superior Gold'	8 × 15	166.2a[z]	7.5b	13.3b	5.7b	58.0a
	15 × 15	171.0a	8.6b	14.6b	6.4a	58.9a
	23 × 23	178.5a	10.2a	15.3a	6.8a	59.4a
	30 × 30	180.4a	11.5a	17.1a	7.9a	58.5a
'ProCut Gold Lite DMR'	8 × 15	123.6a	6.3b	9.5b	4.3b	49.9a
	15 × 15	117.0a	7.4a	10.4a	4.9a	50.5a
	23 × 23	124.0a	8.5a	11.8a	6.2a	49.5a
	30 × 30	114.8a	8.9a	11.7a	5.6a	50.8a
'Sunrich Lemon'	8 × 15	123.3a	6.4a	10.8a	5.2a	65.2a
	15 × 15	117.4a	6.1a	10.4a	5.1a	63.9b
	23 × 23	107.7a	6.0a	10.6a	4.8a	68.4a
	30 × 30	116.3a	7.6a	12.4a	5.9a	66.9a
Significance	Cultivar	0.8864	<.0001	<.0001	<.0001	0.0032
	Spacing	<.0001	<.0001	<.0001	<.0001	<.0001
	Interaction	0.0059	0.0078	0.0332	0.0019	0.0003

[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.

Flower Size Distribution

In expt. 1A, the percentage of each sunflower size changed as spacing increased (Table 1.6). Similarly, the percentage of each sunflower size increased with increasing cultivar vigor. The 8 × 15 cm spacing treatment produced the greatest percentage of unmarketable flowers (culls) for all three cultivars. All three cultivars had a general trend of increasing percentage of larger flowers with increasing spacing treatment. As spacing increased, flower size distribution increased the percentage of larger flowers.

In expt. 1B, the percentage of each sunflower size changed as spacing increased (Table 1.7). Similarly, the percentage of each sunflower size increased with increasing cultivar vigor. The 8 × 15 cm spacing treatment produced the greatest percentage of unmarketable flowers for all three cultivars. Cultivars ‘Superior Gold’ and ‘ProCut Gold’ had a general trend of increasing percentage of large flowers with increasing spacing treatment. Cultivar ‘Sunrich Lemon’ had the greatest percentage of medium flowers in all four spacing treatments.

In expt. 2A, the frequency of flower size classes clearly shows the influence of spacing on flower size distribution (Table 1.8). The percentage of each sunflower size changed as spacing increased. The 8 × 15 cm spacing treatment produced the greatest percentage of unmarketable flowers (culls) for all three cultivars. Although the treatment means were above marketable disk diameter, even the 8 × 15 cm spacing, there were a number of flowers that were below the minimum marketable size. Cultivar ‘Superior Gold’ had a general trend of an increasing percentage of large flowers with increased spacing. Cultivar ‘ProCut Gold’ had a general trend of an increasing percentage of medium flowers with increasing spacing treatment.

In expt. 2B, the frequency of flower size classes clearly shows the influence of spacing on flower size distribution (Table 1.9). The percentage of each sunflower size changed as spacing increased. Cultivars ‘Superior Gold’ and ‘Sunrich Lemon’ had the greatest percentage of unmarketable flowers at the 15 × 15 cm spacing treatment. Cultivar ‘ProCut Gold Lite DMR’ had the greatest percentage of unmarketable flowers at the 8 × 15 cm spacing treatment. Although the treatment means were above the marketable disk diameter, even the 8 × 15 cm spacing, there were a number of flowers that were below the minimum marketable size. Cultivar ‘Superior Gold’ had a general trend of an increasing percentage of large flowers with increased spacing.

Flower Marketability

In expt. 1A, for flower marketability the 8 × 15 cm spacing and the most vigorous cultivar ‘Superior Gold’ had the greatest net revenue per m^2 ($63.55) (Table 1.10). There was a decrease in the net revenue as spacing increased. The 8 × 15 cm spacing treatment produced $49.11 per m^2 followed by 15 × 15 cm ($35.12), 23 × 23 cm ($20.97), and 30 × 30 cm ($13.11). All three cultivars showed a general trend of decreasing net revenue per m^2 with increased spacing treatment. The most vigorous cultivar ‘Superior Gold’ produced the greatest net revenue per m^2 ($38.20) compared to ‘ProCut Gold’ ($25.83) and ‘Sunrich Lemon’ ($24.72).

In expt. 1B, for flower marketability there was an increase in the net revenue between spacing treatments (Table 1.11). The most vigorous cultivar ‘Superior Gold’ in combination with the 8 × 15 cm spacing treatment had the greatest net revenue per m^2 ($80.03). The 8 × 15 cm spacing treatment produced $63.21 per m^2 followed by 15 × 15 cm ($38.53), 23 × 23 cm ($18.62), and 30 × 30 cm ($12.52). All three cultivars showed a general trend of decreasing net revenue per m^2 with increased spacing treatment. The most vigorous cultivar ‘Superior Gold’ produced the greatest net revenue per m^2 ($42.47) compared to ‘ProCut Gold’ ($31.75) and ‘Sunrich Lemon’ ($25.45).

In expt. 2A, for flower marketability there was a difference in the net revenue between spacing treatments (Table 1.12). The 8 × 15 cm spacing treatment produced $57.90 per m^2 followed by 15 × 15 cm ($41.91), 23 × 23 cm ($20.73), and 30 × 30 cm ($13.29). The ‘Superior Gold’ cultivar planted at 8 × 15 cm spacing had the highest revenue per m^2 ($73.44). All three cultivars showed a general trend of decreasing net revenue per m^2 with increased spacing treatment. The most vigorous cultivar ‘Superior Gold’ produced the greatest net revenue per m^2 ($41.71) compared to ‘ProCut Gold’ ($30.24) and ‘Sunrich Lemon’ ($28.42). Although there was a high percentage of unmarketable sunflowers in the 8 × 15 cm spacing the increased number of flowers per m^2 resulted in a greater net revenue per m^2. As spacing increased the percentage of larger flowers increased, but the lower number of flowers yielded lower revenues per m^2.

In expt. 2B, for flower marketability there was a significant decrease in the net revenue between spacing treatments (Table 1.13). The 8 × 15 cm spacing treatment produced \$59.84 per m^2 followed by 15 × 15 cm (\$32.48), 23 × 23 cm (\$16.12), and 30 × 30 cm (\$10.93). The ‘Superior Gold’ cultivar planted at 8 × 15 cm spacing had the highest revenue per m^2 (\$69.36). All three cultivars showed a general trend of decreasing net revenue per m^2 with increased spacing treatment. The most vigorous cultivar ‘Superior Gold’ produced the greatest net revenue per m^2 (\$34.19) compared to ‘Sunrich Lemon’ (\$30.29) and ‘ProCut Gold Lite DMR’ (\$25.05). Although there was a high percentage of unmarketable sunflowers in the 8 × 15 cm spacing, the increased number of flowers per m^2 resulted in greater net revenue per m^2. As spacing increased, the percentage of larger flowers increased, but the lower number of flowers yielded lower revenue per m^2.

Table 1.6. Effect of spacing on ‘Superior Gold,’ ‘ProCut Gold,’ and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) percentage of marketable flowers, Expt. 1A.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
‘Superior Gold’	Culls	33% (27)[z]	10% (5)	1% (0)	0% (0)
	Small	13% (11)	13% (6)	1% (0)	1% (0)
	Medium	31% (26)	33% (14)	26% (5)	18% (2)
	Large	23% (19)	44% (19)	72% (14)	81% (9)
‘ProCut Gold’	Culls	44% (37)	32% (14)	9% (2)	3% (0)
	Small	33% (27)	26% (12)	18% (3)	3% (0)
	Medium	22% (18)	39% (17)	55% (11)	39% (5)
	Large	1% (1)	3% (1)	18% (3)	55% (6)
‘Sunrich Lemon’	Culls	46% (41)	36% (16)	12% (2)	23% (2)
	Small	18% (14)	21% (9)	10% (2)	7% (1)
	Medium	30% (24)	35% (16)	55% (11)	35% (4)
	Large	5% (4)	8% (3)	23% (4)	35% (4)

[z] Actual number of flowers in each category, 83, 44, 19, 11

Table 1.7. Effect of spacing on ‘Superior Gold,’ ‘ProCut Gold,’ and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) percentage of marketable flower, Expt. 1B.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
‘Superior Gold’	Culls	15% (13)[z]	7% (3)	9% (2)	0% (0)
	Small	15% (13)	10% (4)	5% (1)	4% (0)
	Medium	41% (34)	33% (15)	20% (4)	16% (2)
	Large	28% (23)	50% (22)	66% (12)	81% (9)
‘ProCut Gold’	Culls	27% (22)	22% (10)	11% (2)	7% (1)
	Small	31% (26)	24% (11)	16% (3)	9% (1)
	Medium	39% (32)	43% (19)	40% (8)	19% (2)
	Large	3% (3)	11% (4)	33% (6)	65% (7)
‘Sunrich Lemon’	Culls	43% (35)	32% (14)	31% (6)	31% (4)
	Small	21% (18)	28% (12)	25% (5)	12% (1)
	Medium	22% (19)	34% (15)	38% (7)	39% (4)
	Large	14% (11)	6% (3)	6% (1)	18% (2)

[z] Actual number of flowers in each category, 83, 44, 19, 11

Table 1.8. Effect of spacing on' Superior Gold,' 'ProCut Gold,' and 'Sunrich Lemon' sunflowers (*Helianthus annuus*) percentage of marketable flowers, Expt. 2A.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
'Superior Gold'	Culls	17% (14)[z]	1% (1)	1% (1)	0% (0)
	Small	26% (22)	15% (7)	10% (2)	0% (0)
	Medium	38% (31)	36% (15)	24% (4)	14% (2)
	Large	19% (16)	48% (21)	65% (12)	86% (9)
'ProCut Gold'	Culls	27% (22)	16% (7)	6% (1)	3% (1)
	Small	45% (38)	39% (17)	26% (5)	9% (1)
	Medium	26% (21)	41% (18)	57% (11)	67% (7)
	Large	2% (2)	4% (2)	10% (2)	21% (2)
'Sunrich Lemon'	Culls	42% (35)	14% (6)	6% (1)	0% (0)
	Small	37% (31)	38% (17)	23% (5)	16% (2)
	Medium	18% (15)	37% (16)	44% (8)	52% (6)
	Large	2% (2)	10% (5)	26% (5)	32% (3)

[z] Actual number of flowers in each category, 83, 44, 19, 11

Table 1.9. Effect of spacing on 'Superior Gold,' 'ProCut Gold Lite DMR,' and 'Sunrich Lemon' sunflowers (*Helianthus annuus*) percentage of marketable flowers, Expt. 2B.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
'Superior Gold'	Culls	23% (19)	31% (14)	17% (3)	9% (1)
	Small	27% (23)	11% (5)	22% (4)	6% (1)
	Medium	27% (23)	30% (13)	19% (4)	29% (3)
	Large	22% (18)	27% (12)	42% (8)	55% (6)
'ProCut Gold Lite DMR'	Culls	42% (35)	34% (15)	21% (4)	6% (1)
	Small	34% (28)	26% (11)	23% (4)	41% (4)
	Medium	22% (19)	29% (13)	43% (8)	46% (5)
	Large	2% (1)	11% (5)	13% (3)	7% (1)
'Sunrich Lemon'	Culls	24% (20)	24% (11)	23% (4)	18% (2)
	Small	27% (22)	44% (19)	47% (9)	29% (3)
	Medium	34% (29)	22% (10)	26% (5)	32% (4)
	Large	15% (12)	9% (4)	4% (1)	21% (2)

[z] Actual number of flowers in each category, 83, 44, 19, 11

Table 1.10. Effect of spacing on ‘Superior Gold,’ ‘ProCut Gold,’ and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) on net revenue per m^2, Expt. 1A.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
‘Superior Gold’	$0.85	$9.02	$4.89	$0.21	$0.15
	$1.00	$25.57	$14.39	$4.87	$1.95
	$1.50	$28.96	$28.99	$20.46	$13.31
	Total	$63.55	$48.28	$25.54	$15.41
‘ProCut Gold’	$0.85	$23.03	$9.62	$2.86	$0.30
	$1.00	$18.21	$17.18	$10.58	$4.26
	$1.50	$1.27	$1.89	$5.05	$9.05
	Total	$42.51	$28.69	$18.49	$13.61
‘Sunrich Lemon’	$0.85	$12.15	$7.70	$1.66	$0.66
	$1.00	$24.19	$15.53	$10.53	$3.86
	$1.50	$4.94	$5.17	$6.71	$5.79
	Total	$41.28	$28.40	$18.90	$10.31

Table 1.11. Effect of spacing on ‘Superior Gold,’ ‘ProCut Gold,’ and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) on net revenue per m^2, Expt. 1B.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
‘Superior Gold’	$0.85	$10.85	$3.78	$0.85	$0.33
	$1.00	$34.05	$14.67	$3.75	$1.74
	$1.50	$35.12	$32.66	$18.75	$13.32
	Total	$80.03	$51.11	$23.35	$15.38
‘ProCut Gold’	$0.85	$22.00	$9.13	$2.54	$0.81
	$1.00	$32.25	$18.93	$7.60	$2.09
	$1.50	$4.57	$6.91	$9.37	$10.81
	Total	$58.82	$34.97	$19.50	$13.70
‘Sunrich Lemon’	$0.85	$14.99	$10.34	$3.97	$1.13
	$1.00	$18.68	$14.98	$7.16	$4.33
	$1.50	$17.12	$4.21	$1.87	$3.00
	Total	$50.79	$29.53	$13.00	$8.47

Table 1.12. Effect of spacing on ‘Superior Gold,’ ‘ProCut Gold,’ and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) on net revenue per m^2, Expt. 2A.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
‘Superior Gold’	$0.85	$18.58	$5.83	$1.64	$0.00
	$1.00	$31.17	$15.74	$4.57	$1.55
	$1.50	$23.68	$31.49	$18.40	$14.18
	Total	$73.44	$53.07	$24.61	$15.73
‘ProCut Gold’	$0.85	$31.78	$14.49	$4.24	$0.89
	$1.00	$21.36	$18.23	$10.93	$7.33
	$1.50	$3.09	$2.38	$2.85	$3.40
	Total	$56.23	$35.10	$18.01	$11.63
‘Sunrich Lemon’	$0.85	$26.46	$14.33	$3.78	$1.51
	$1.00	$14.88	$16.45	$8.39	$5.68
	$1.50	$2.70	$6.78	$7.40	$5.32
	Total	$44.04	$37.56	$19.57	$12.51

Table 1.13. Effect of spacing on ‘Superior Gold,’ ‘ProCut Gold Lite DMR,’ and ‘Sunrich Lemon’ sunflowers (*Helianthus annuus*) on net revenue per m^2. Expt, 2B.

Cultivars		8 × 15 cm	15 × 15 cm	23 × 23 cm	30 × 30 cm
‘Superior Gold’	$0.85	$19.33	$4.20	$3.51	$0.62
	$1.00	$22.74	$13.35	$3.58	$3.18
	$1.50	$27.29	$17.80	$11.98	$9.17
	Total	$69.36	$35.35	$19.07	$12.97
‘ProCut Gold Lite DMR’	$0.85	$24.04	$9.64	$3.66	$3.81
	$1.00	$18.55	$12.70	$8.11	$5.09
	$1.50	$2.09	$7.48	$3.80	$1.22
	Total	$44.69	$29.83	$15.57	$10.12
‘Sunrich Lemon’	$0.85	$18.93	$16.62	$7.62	$2.75
	$1.00	$28.34	$9.78	$5.02	$3.56
	$1.50	$18.21	$5.87	$1.07	$3.40
	Total	$65.49	$32.26	$13.71	$9.71

Discussion

The marketability of specialty cut sunflowers is determined by the stem length, stem diameter, flower diameter, and disk diameter. In expt. 1A the cultivar ‘ProCut Gold’, stem length increased as spacing increased (Table 1.2). In expt. 2A stem lengths of cultivars ‘ProCut Gold’ and ‘Sunrich Lemon’ increased as spacing increased (Table 1.4). In expt. 2B stem length of cultivar ‘Superior Gold’ increased as spacing increased (Table 1.5). This observation is inconsistent with previous research (Burnett, 2017; Cheema, 2018; Wien, 2012). Cheema’s (2018) study conducted at Stephen F. Austin State University found stem lengths of cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing to be 184.9 cm with stem length of 160.9 cm at 30 × 30 cm spacing, which is a 15% decrease. Similarly, Burnett (2017) and Wien (2012) found that stem lengths decreased between the 15 × 15 cm spacing and 30 × 30 cm spacing by 3% and 4%, respectively. In expt. 1A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing produced stem lengths of 191.3 cm, but stem lengths of 227.4 cm at 30 × 30 cm spacing, which is an 18.9% increase in stem length. In expt. 2A the cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing produced a stem length of 198.7 cm, with a stem length of 233.2 cm at 30 × 30 cm spacing, which is a 17% increase in stem length. This trend of increasing stem length with increased spacing is also not consistent with research on plant reactions to red to far-red light ratios. Previous research has shown that plants receiving shade from neighboring plants will have increased stem lengths (Nozue et al., 2015; Libenson et al., 2002).

In expts. 1A, 2A, and 2B stem diameter increased as spacing increased for all four cultivars: ‘Superior Gold,’ ‘ProCut Gold,’ ‘ProCut Gold Lite DMR,’ ‘Sunrich Lemon’ (Tables 1.2, 1.4, and 1.5). In expt. 1B cultivars ‘Superior Gold’ and ‘ProCut Gold’ stem diameter increased with increased spacing (Table 1.3). This trend is consistent with previous research on sunflower spacing (Burnett, 2017; Cheema, 2018; Wien, 2012). Cheema (2018) found stem diameters of the cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing to be 6.3 mm, with stem diameters of 8.9 mm at 30 × 30 cm spacing, which is a 41% increase. Similarly, Burnett (2017) had a stem diameter increased between the 15 × 15 cm spacing and 30 × 30 cm spacing by 37%. In expt. 1A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing and 30 × 30 cm spacing increased for stem diameter by 36%. In expt. 2A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing produced stem diameters of 7.54 cm, but stem diameters of 11.5 cm at 30 × 30 cm spacing, which is an 81% increase in stem diameter.

In expts. 1A, 2A, and 2B flower diameter increased as spacing increased for all four cultivars (Tables 1.2, 1.4, and 1.5). In expt. 1B cultivars ‘Superior Gold’ and ‘ProCut Gold’ flower diameter increased with increased spacing

(Table 1.3). This trend is consistent with previous research on sunflower spacing (Burnett, 2017; Cheema, 2018; Wien, 2012). Cheema (2018) showed a 15% increase in flower diameter between the 8 × 15 cm and 30 × 30 cm spacing. Similarly, Burnett (2017) and Wien (2012) observed that flower diameter increased between the 15 × 15 cm spacing and 30 × 30 cm spacing treatments by 17% and 40%, respectively. In expt. 1A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing and 30 × 30 cm spacing increased flower diameter by 36%. In expt. 2A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing produced flower diameters of 13.3 cm, but flower diameters of 17.1 cm at 30 × 30 cm spacing, which is a 57% increase in flower diameter.

In expt. 1A cultivars ‘Superior Gold’ and ‘Sunrich Lemon’ disk diameter increased with increased spacing (Table 1.2). In expt. 1B cultivars ‘Superior Gold’ and ‘ProCut Gold’ disk diameter increased with increased spacing (Table 1.3). In expts. 2A and 2B disk diameter increased with increased spacing with all four cultivars (Tables 1.4 and 1.5). This trend is consistent with previous research (Cheema, 2018). Cheema (2018) found that the disk diameter of cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing 6.2 cm, with the 30 × 30 cm spacing averaged 6.5 cm, which is a 6% increase. In expt. 1A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing produced disk diameters of 6.1 cm but disk diameters of 9.0 cm at 30 × 30 cm spacing, which is a 47% increase in disk diameter. In expt. 2A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing produced a disk diameter of 5.1 cm, but a disk diameter of 9.4 cm at 30 × 30 cm spacing, which is an 84% increase in disk diameter.

In expt. 1A cultivars ‘Superior Gold’ and ‘Sunrich Lemon’ days-to-harvest decreased with increased spacing (Table 1.2). In expt. 2A the days-to-harvest of cultivar ‘Superior Gold’ decreased as spacing increased (Table 1.4). Cultivars ‘Superior Gold’ and ‘Sunrich Lemon’ had longer days-to-harvest than previous research (Table 1.1) while ‘ProCut Gold’ had shorter days-to-harvest. Cheema (2018) found days-to-harvest of cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing to be 60.13 days, with days-to-harvest of 56.4 days at 30 × 30 cm spacing, which is a 7% decrease. In expt. 1A cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing averaged 72.3 days-to-harvest, but days-to-harvest were 69.7 days at 30 × 30 cm spacing, which is a 4% decrease in days-to-harvest. In expt. 2A days-to-harvest of cultivar ‘Superior Gold’ planted at 8 × 15 cm spacing were 66.3 days, but days-to-harvest were 64.6 days at 30 × 30 cm spacing, which is a 3% decrease in days-to-harvest.

Previous research on the effect of temperature on sunflower growth has found that higher temperatures lead to decreased chlorophyll levels and leaf mass (Haba et al., 2020). Decreased chlorophyll levels lead to reduced growth and development of the plant. The optimal temperature range for sunflower growth is 22–30°C (Schoellhorn et al., 2003). Expt. 1A had average temperatures of 16°C, 24°C, and 28°C in April, May, and June, respectively (NOAA, 2021). Expt. 1B had average temperatures of 28°C, 29°C, 27°C, and 25°C in June, July, August, and September, respectively (NOAA, 2021). Expt. 2A had average temperatures of 21°C, 25°C, and 27°C in May, June, and July, respectively (NOAA, 2021). In expt. 2B average temperatures were 27°C, 27°C, and 23°C in July, August, and September, respectively (NOAA, 2021). Wien's (2012) experiment conducted at Cornell University, Ithaca, NY, had a high average temperature of 22.7°C, below the optimal temperature range for sunflower growth. This could explain why Wien's experiment produced smaller sunflowers.

In expts. 1A and 1B, the frequency of flower size classes clearly shows the influence of spacing on flower size distribution (Tables 1.6 and 1.7). In expt. 1A, all three cultivars had a general trend of increasing percentage of large flowers with increasing spacing treatment. In expt. 1B, cultivars 'Superior Gold' and 'ProCut Gold' had a general trend of increasing percentage of large flowers with increasing spacing treatment. Although there was a high percentage of unmarketable sunflowers in the 8 × 15 cm spacing in expts. 1A and 1B, the increased number of flowers per m^2 resulted in greater net revenue per m^2. As spacing increased there is an increased percentage of larger flowers. For example, in expt. 1A cultivar 'Superior Gold' produced 23% large flowers at the 8 × 15 cm spacing and 81% at the 30 × 30 cm, which is a 246% increase.

However, there was a lower number of flowers yielded per m^2, producing lower revenue per m^2.

In expts. 2A and 2B, the frequency of flower size classes clearly shows the influence of spacing on flower size distribution (Tables 1.8 and 1.9). In expts. 2A and 2B, cultivar ‘Superior Gold’ had a general trend of increasing percentage of large flowers with increasing spacing treatment. In expt. 2A, cultivar ‘ProCut Gold’ had a general trend of increasing percentage of medium flowers with increasing spacing treatment. As spacing increased there is an increased percentage of larger flowers. For example, in expt. 2A cultivar ‘Superior Gold’ produced 19% large flowers at the 8 × 15 cm spacing and 85.94% at the 30 × 30 cm, which is a 352% increase.

In expts. 1A and 1B, for flower marketability the most vigorous cultivar ‘Superior Gold’ and the 8 × 15 cm spacing had the greatest net revenue per m^2 (Tables 1.10 and 1.11). In both expts. all three cultivars showed a general trend of decreasing net revenue per m^2 with increased spacing treatment. With decreased spacing, there can be more plants grown in an 8 × 15 cm spacing plot allowing for land to be used for more sunflowers or other cash crops.

In expts. 2A and 2B, for flower marketability the most vigorous cultivar ‘Superior Gold’ and the 8 × 15 cm spacing had the greatest net revenue per m^2 (Tables 1.12 and 1.13). Although there was a high percentage of unmarketable sunflowers in the 8 × 15 cm spacing in expts. 2A and 2B, the increased number of flowers per m^2 resulted in greater net revenue per m^2. In both expts. all three cultivars showed a general trend of decreasing net revenue per m^2 with increased spacing treatment. With decreased spacing, there can be more plants grown in an 8 × 15 cm spacing plot, allowing for land to be used for more sunflowers or other cash crops.

Conclusion

The results of these two spacing experiments conducted at Stephen F. Austin State University in East Texas demonstrated that the most profitable specialty cut sunflower spacing is 8 × 15 cm. Stem length increased as spacing treatments increased in both experiments. In experiments 1 and 2 stem length increased by 19% and 17% between the 8 × 15 cm and the 30 × 30 cm spacing, respectively. Stem diameter increased as spacing treatments increased in both experiments. In experiments 1 and 2, stem diameter increased by 36% and 81% between the 8 × 15 cm and the 30 × 30 cm spacing, respectively. Flower diameter increased as spacing treatments increased in both experiments. In experiments 1 and 2, flower diameters increased by 36% and 57% between the 8 × 15 cm and the 30 × 30 cm spacing, respectively. Disk diameter increased as spacing treatments increased in both experiments. In experiments 1 and 2, disk diameter increased by 47% and 84% between the 8 × 15 cm and the 30 × 30 cm spacing, respectively. Days-to-harvest decreased as spacing treatments increased in both experiments. In experiments 1 and 2, days-to-harvest decreased by 4% and 3% between the 8 × 15 cm and the 30 × 30 cm spacing, respectively. While the 30 × 30 cm spacing treatment produced the largest flowers in both experiments, the 8 × 15 cm spacing produced the greatest revenue per m^2 in both experiments. There was a decrease in net revenue per m^2 with increased spacing treatments in both experiments. The most vigorous cultivar 'Superior Gold' produced the greatest revenue per m^2 for all four spacing treatments.

The current recommendation for specialty cut sunflower spacing is 15 × 15 cm spacing (Schoellhorn et al., 2003). Analysis of these two experiments determined the most profitable spacing of specialty cut sunflowers grown in East Texas is 8 × 15 cm regardless of cultivar vigor. Growers in East Texas should consider the quality and quantity of flowers they want to produce when choosing a spacing treatment. Growers should also consider the vigor of the cultivar when choosing a spacing treatment.

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