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# Optimum Planting Dates for Garlic in Southwest Missouri

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# OPTIMUM PLANTING DATES FOR GARLIC IN SOUTHWEST MISSOURI

A Master's Thesis

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In Partial Fulfillment

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Master of Science, Plant Science

By

Esther Ann Nelson

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## ABSTRACT

Garlic (*Allium sativum*) is one of the most widely used spices in the world. More research is needed to outline the best growing practices for garlic in Southwest Missouri. The study is designed to look the yield produced by four different fall planting and one spring date. Three varieties of garlic including Inchilium Red, German White and Elephant were planted on each date at two separate locations in Southwest Missouri for one year. The garlic was found to have highly diverse yields at both locations and when planting dates where compared. Elephant garlic produced the highest yield when planted in late September at the Darr farm while no difference in yield was found at the Braker farm between the fall planting dates. The German white garlic was largest when planted in early October at the Darr farm and largest when planted in mid-September and early-October at Braker. Inchilium Red at Darr was largest from late September and early October, while no difference was between the fall dates at the Braker farm. Overall spring resulted in smaller yields for all varieties.

**KEYWORDS**: garlic, planting dates, Southwest Missouri, Ozarks, fall, spring

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# INTRODUCTION

Garlic (*Allium sativum* L.) has become an increasingly popular crop. Garlic is considered as one of the most important species in the onion family (Amaryllidaceae) (Fanaei et al., 2014). Garlic comes second only to onion in the *sativum* family when considering the amount grown across the world (Walters, 2008). The bulb is prized for its flavor and for its ability to alleviate many aliments from which people suffer. Garlic has a higher nutritional value than other bulb crops (Naruka and Dhaka, 2001). It can be added to foods, taken as a supplement, or even eaten as a raw food item, although the powders and the capsules do contain significantly less medicinal activity (Invista, 2016).

More research is needed to inform farmers of the potential profit that can be made by growing this crop. Additional research is needed on the type of garlic, planting dates and other growing practices for garlic in specific regions. Growers are looking for ways to increase their revenue on their land. Garlic can sell between $2 to $4 a pound which totals between $1,400 to $3,200 per acre (Bachmann and Hinman, 2008). If garlic can be proven to be a profitable crop, more farmers may be willing to grow it. The demand for garlic has increased considerably in the recent years and its economic importance could encourage farmers to consider garlic as one of their crops (Youssef and Tony, 2014).

The knowledge of planting practices for garlic in Southwest Missouri is very limited. The planting date significantly affects garlic's ability to produce quality bulbs. Garlic must be planted early enough to grow a root system before the first frost. There is a fine line between too much and too little vegetative growth that is produced before freezing temperatures occur. As pointed out by Raham and Talukda (1986), yields are dependent on the amount of vegetation produced before bulb formation begins. Many contributing factors including fertilization, space between rows and irrigation requirements influence the growth of garlic bulbs (Hassan, 2015). There are other environmental conditions that affect garlic development including soil, photoperiod and temperature (El-Zohiri and Farag, 2014). This study has focused on the yield and quality of garlic planted on different dates.

The United States imports most its garlic from China. China dominates the garlic industry, perhaps more than any other food product sold in the United States (Lipka, 2011). The United States can decrease the amount it imports by increasing the availability of locally grown garlic. More people want to have a larger selection of food to choose from when shopping at their local farmer’s markets and grocery stores. Garlic fits well into farmer’s markets and grocery store offerings because of its long shelf life when properly cured. Southwest Missouri has the proper climate and soil conditions to produce garlic, which can be grown in many environments.

We hope our research findings convince more growers in this region to add garlic to their production. While the growers can increase their profits, local communities will have more options to choose from when searching for locally grown foods. This could boost local economies and allow people to interact with each other at markets. Local populations can become more aware of from where their food comes. They can also become more knowledgeable about what inputs are used to produce the foods they are consuming.

## LITERATURE REVIEW

### History of Garlic

Garlic is believed to have originated in Central Asia (Food Talk, 1978). One of the earliest references to this perennial was found to be around the sixth century B.C. (Dannester, 2003). Dannester reported that Sumerians used garlic for its healing properties between 2600-2100 BC. It is thought that they brought the garlic to China and from there it spread to Japan and Korea (Cekovska and Petrovska, 2010). Asia wasn't the only region found to be using garlic: it was also found in King Tutt's tomb (Straus, 1997). The Egyptians had at least Twenty-two garlic prescriptions used for such purposes as treating headaches and throat disorders. There are numerous medicinal uses for garlic in Asian, Chinese and Indian cultures (Invista, 2016). Garlic was introduced into the United States around the 1700s but didn't start growing in popularity until the 1920s (Boriss, 2014). Currently it is one of the most popular spices in the world.

The United States imports more garlic than any other country in the world but ranks only eighth in production. California produces most of the garlic grown in the United States, but Nevada and Oregon also contribute (Boriss, 2014). California produces around eighty-five percent of the U.S. garlic while Oregon and Nevada provide an additional five to six percent (Walters, 2008).

### General Garlic Information

Garlic is a perennial plant that belongs to the Amaryllidaceae family. It has as a tall, thin stalk with narrow leaves and many varieties produce a round, puffy inflorescence (Starbucks, 1999). Garlic is closely related to onions and is also typically grown for its flavorful bulbs, although all parts of garlic are edible except for the roots and the paper-like covering that encloses each clove (Encyclopedia Britannica, 2016). Garlic greens are the leaves that are produced in the fall before the first frost kills them and, in some climates, can be harvested a few times before freezing occurs. A common way to consume them is to make a garlic greens pesto (Bachmann and Hinman, 2008).

There are two species of garlic: hard-neck (*Allium ophioscorodon*) and soft-neck (*Allium sativum*). Hard-neck garlic is easily identified by the long flower stalk, commonly referred to as the scape, and the flower-like bulbils (tiny secondary bulbs that form in place of flowers) in some varieties. The scapes are sometimes cut from the plant while tender and no longer than 16 inches or over one-fourth inch diameter (Bachmann and Hinman, 2008). Another way to identify hard-neck garlic is the orientation and number of layers of cloves (Figure 1). Hard-neck varieties have a single layer of six to eight cloves arranged around the flower stalk (Walters, 2008). Research has shown that hard-neck garlic tends to be more winter hardy and produces higher yields than soft-neck varieties (Martini, 2015).

Soft-neck varieties are sometimes used for braiding because they do not have the hard stalk growing up the center (Walters, 2008). Soft-neck garlic is characterized by the absence of the scape and typically does not produce bulbils. Their cloves are arranged in three to six layers around each other (Figure 2), totaling somewhere between twelve to twenty-five cloves per bulb (Walters, 2008). The outer layer tends to have the larger cloves while the inside layers of cloves become smaller and smaller (Bachmann and Hinman, 2008).

A garlic bulb consists of a basal plate that holds the cloves, which are a series of functional leaves, according to Dufoo-Hurtado et al. (2013). Each clove is covered by “cataphylls”. These vegetative buds are dormant until they are exposed to the right environmental growing conditions (Dufoo-Hurtado et al., 2013). Garlic is propagated by separating and planting individual cloves. The plant itself is typically sterile (Bandara et al., 2000).

**Uses of Garlic**

Americans consume or use an average of two pounds of garlic each year and the amount has steadily increased (Boriss, 2014).

Garlic can be enjoyed raw, sautéed, in soups, aiolies, or pestos (Loomis, 2011). It is a very versatile food. People enjoy garlic in spring rolls, stir fry, stuffed mushrooms, corn on the cob (garlic salt) and artichokes (garlic butter). It has even been added to sweets such as garlic chocolate ice cream and garlic chocolate peanut butter cups (Straus, 1997).

Garlic is the most studied herb in history (Crayon, 1997). The medicinal uses are almost as numerous as the culinary uses. Around 1858, Louis Pasteur discovered that it could kill bacteria (Hall, 1994). Studies have shown garlic can prevent heart disease, fungal overgrowth and infectious diseases (Crayon, 1997). At the World Congress on Health Significance of Garlic and Garlic Constituents held in Washington in August 1990, attendees discussed garlic’s ability to remove toxic metals from the body and garlic’s powerful antioxidant and anti-cancer effects (Crayhon, 1997).

At least two hundred compounds have been identified in garlic (Crayhon, 1997). Some of the most beneficial are sulfur compounds (alliin, allicin, diallyl sulfide, ajoene, etc.), cellulose, amino acids, lipids, etheric oil, complexes of fructosans (carbohydrates), steroid saponosides, organic acids, minerals (Mg, Zn, Se, germanium), vitamins (C, A, B complex), enzymes and more (Cekovska and Petrovska, 2010). Garlic supplements have been well studied and are available for purchase. Many forms of garlic supplements are sold including oils, powders, cold-water aqueous extract and fermented garlic extract (Starbucks, 1999).

The allicin and other sulfur compounds provide antibacterial action. When a garlic clove is bruised, sliced or crushed, the enzyme allinase is released. It then converts alliin to allicin (Hall, 1994). Allicin also benefits the respiratory system (Cekovska and Petrovska, 2010).

Clinical studies have shown that garlic reduced blood pressure in more than eighty percent of patients (Bayan et al., 2014). Eating up to a clove of garlic a day was associated with cholesterol levels dropping about nine percent (Hall, 1994). Garlic can also boost the immune system, balance blood sugar and prevent heart disease. It prevents heart disease in two ways: reducing free radicals that cause damage to cholesterol and inhibiting the infiltration of damaged fats and cholesterol through the wall of our arteries (Crayhon, 1997). No reported side effects have been associated with garlic consumption, unlike many of the other synthetic offerings (Bayan et al., 2014).

Garlic may be the most potent food that has cancer preventative properties. Some of the anti-tumor effects include the inhibition of cell growth and chemo preventive effects

(Bayan et al., 2014). In recent years, there has been a significant increase in the popularity of "natural" medicines and "natural" products (Bayan et al., 2014). This has renewed interest in garlic and its derivatives as potential natural remedies.

**Common Growing Practices**

Many research studies have focuses on the best growing practices for garlic throughout the United States and the world. Garlic is best grown in soil that has a pH between 6.8 to 7.2 (Bachmann and Hinman, 2008). The ideal soil has high nutrient availability and organic matter. Because garlic is a high value crop and uses large amounts of nutrients, growers should devote their best ground to growing it (Bachmann and Hinman, 2008). Adding three to four pounds of 10-10-10 fertilizer per one hundred square feet when preparing soil should result in high yields (Bratsch, 2003). Pennsylvania State University Extension specialists recommend applying the equivalent of seventy- five pounds of N per acre at planting, a twenty-five-pound application when the plants are six inches tall, and twenty-five pounds around May 1 (Ford et al., 2015).

If possible, garlic should be grown on raised beds to aid in drainage of the soil. This will slow down the degradation of the wrappers around the cloves (Bratsch, 2009). Raised beds also reduce compaction and make digging easier when it is time to harvest (Bachmann and Hinman, 2008).

The bulbs should be exposed to temperatures of around 41 ºF (5 ºC) for fifteen to thirty days before planting, which accelerates the initiation, development and maturity of the cloves (Dufoo-Hurtado et al., 2013).

The garlic bulb should remain intact until it is time to plant, and then each bulb should be broken into individual cloves. Larger bulbs have more cloves and yield larger plants, which should be considered when choosing which bulbs are saved for planting (Bratsch, 2003). As Volk et al. (2009) stated, “High yields are dependent on having initial planting stock that is of sufficient size and quality.”

Garlic does not compete well with other plants, so cloves should be planted about four to six inches apart (Bachman, 2009). The best planting densities were between two to four plants per square foot (Castellanos et al., 2004).

Each clove should be planted with the basal plate down. Mechanical planting is sometimes used but proper orientation of the cloves cannot be guaranteed. When planted upside down, growth tends to be uneven and slow, so ultimately yield and quality can be reduced (Castellanos et al., 2004).

According to research conducted in Canada fall is the best time to plant garlic since fall-planted garlic has a higher number of cloves on each bulb and a higher overall yield, compared to spring-planted garlic (Bandara et al., 2000). Although fall is widely accepted as the best time to plant specific fall planting dates have yet to be confirmed within the Southwest Missouri region. It is well known that not one practice is well suited for every situation (Ford, 2014). During our research we will attempt to discover, within the fall months, what is the optimum date for planting garlic to increase overall yield.

Fall planting gives garlic time to sprout in Southwest Missouri and it often overwinters above-ground in the field. It will resume growth in the spring (Volk et al., 2004). Spring regrowth begins in mid-March (Walters, 2008). The formation of the bulbs and cloves depend on the length of the day and the temperature (Bandara et al., 2000). A long photoperiod is required for both dormancy induction axillary buds and clove formation (Kamenetsky et al., 2004).

Mulch is recommended since garlic is a poor competitor with weeds. Garlic emerged sooner and started to grow quicker when black plastic was used (Walters, 2008). Other types of mulch such as straw could be used (Volk et al., 2004). Hand weeding is typically used on a small scale. If machinery is used, care must be taken not to bruise the garlic.

Garlic harvest begins when the lower one third of the leaves begin to brown and dry (Volk and Stern, 2009). Bulb size will double in the last stages of growth (Volk and Stern, 2009). Garlic will stop bulb formation once soil temperatures rise above 90 $^{o}$F (Bachmann and Hinman, 2008). The whole plant is pulled or dug from the ground. Harvested bulbs are typically dried before use (Bratsch, 2009). Garlic is weighed after the curing process has taken place. The bulbs are then stored, transported and/or sold at various locations.

The United States has quadrupled is consumption of garlic since 1980 and the does not show any signs of decline (Ford, 2014). With these numbers increasing growing garlic could be a profitable way for small growers and larger operations to increase profits. As with all crops growing practices greatly affect the amount of revenue one can earn. This research will focus on increasing yield through proper planting dates.

# MATERIALS AND METHODS

The experiments were conducted in 2016 and 2017 at Darr Agricultural Center in Springfield, MO, and Braker Berry Farms in Oronogo, MO. The Darr site was a Newtonia silt loam that was planted in a grass for at least a decade prior to being cultivated for this research. The site in Oronogo was a Barco loam that had been used for various other crops based on the needs of Greg Braker, the farmer that owns the property.

Both sites were plowed and then tilled in the summer, using typical practices. The beds were also disked to break up large clumps of soil. Weeds that germinated before planting were killed with glyphosate.

A 13-13-13 granulated fertilizer from International Plant Food (Cranbury, NJ) was tilled in one day prior to the first planting date (Figure 3). The fertilizer was top-dressed by hand while walking slowly up the raised beds.

Rainfall totals and monthly averages we recorded using the U.S. climate data website (Your weather service, 2019) (Table 1). Maximum, minimum, and monthly average temperatures were also collected via U.S. climate data's website (Your Weather Service, 2019) (Table 2).

A tractor that pulled a three-in-one attachment was used to prepare the beds. The attachment shaped the raised beds while laying down drip line for irrigation and black plastic over the top of the beds (Figure 4). Although the need for pulling weeds was still required, the plastic helped to reduce weed germination and growth. Two ninety-five-foot-long beds were made six feet apart and three feet wide (Figures 5 and 6). A tool invented by

Greg Braker was used to make holes in the plastic and soil at about every four inches (Figure 7). This tool enabled the process of planting to be easier, more accurate and quicker. The pre-punched holes allowed for the wrappers around the cloves to remain more intact during the planting process.

We grew three varieties of garlic, *Allium sativum* 'Inchelium Red' **(**Figure 8) and *Allium sativum* 'German White' (Figure 9)  garlic that were purchased from Keene Organics (Sun Prairie, WI), and *Allium ampeloprsum* 'Elephant' garlic purchased from Territorial Seed Co. (Cottage Grove, OR). German White is a hard-neck variety while the Inchelium Red is a soft-neck variety. Although Elephant garlic (Figures 10 and 11) is more related to leeks than to garlic, we included it in this study because Southwest Missouri producers and consumers grow it using the same practices as with other garlic varieties and consumers use it like regular garlic varieties. The bulbs were placed in a dark, dry and cool area until planting.

The garlic was planted using a complete randomized design. At each location fifty cloves of each variety were planted on each of the planting dates. Each raised bed was divided into plots containing fifty holes per plot. The plots were then numbered, and the garlic was planted at random.  Prior research (Waterer and Schmitz, 1993) discovered that waiting to crack the bulbs until just before planning increases germination rate, so our bulbs were left intact until planting time. Elephant garlic was planted at the ends of each row as border plots. Border plots may help reduce problems with pests of limited mobility or those that are passively dispersed by air currents. The University of Georgia Extension Service recommends the use of border rows because a significant "border effect" may exist at the edge of a field causing plants to grow differently than other plants in the research project (R. Davis et al., 2017).

The fall planting dates were Sept. 22, Oct. 4, Oct. 21 and Nov. 4, 2016 for both planting sites. Elephant garlic was not planted on the first date because the company from whom we purchased it was unable to ship it in time. The spring garlic was planted on Feb. 24, 2017 at each planting site. Each plant from the first four dates received supplemental fertilizer (Figure 12), and Nature's Source liquid fertilizer was added just before planting the spring cloves. The fertilizer was diluted per labeled instructions. Each plant received a quarter cup. A funnel was used to insure accurate placement of the fertilizer within the hole of the plastic directly. Weeds were pulled intermittently. Scapes were removed prior to harvest to encourage significant yield increase (Rosen and Tong, 2001). No irrigation was used.

Garlic was harvested on June 19 at the Braker farm and on June 20 at the Darr location. The garlic with leaves and roots was placed on galvanized metal benches in the Karls Hall Greenhouses (Springfield, MO). Shade cloth was used to omit direct sunlight overhead and supplemental fans were placed in the greenhouses to improve air movement. Data was collected five weeks later after the garlic had dried. Prior to data collection the leaves and roots were trimmed from each clove so as not to be included in the final yield weight.

Garlic bulbs from each plot were weighed to determine yield. Data collection included the weight and diameter of ten of the largest bulbs from each date and variety. Each bulb was broken and the number of cloves per bulb was recorded.

A 3-way design (garlic variety x planting date x planting location) was analyzed to see if there were any reactions between the three variables. A general linear model ANOVA was run for analysis of variance. Data was analyzed using SPSS 19 using the Proc GLM 3-way univariant model.

# DISCUSSION

There was a significant three-way interaction for all data collected (Table 3), possibly due to the presence of two-way interactions for these factors that varied among the data observed. To clarify this information, it was separated by location, by variety and by planting date.

At the Braker Farm location, the spring planting date yielded the smallest bulbs by weight for all three types of garlic (Table 4).

Among Elephant plantings, there were no differences in average bulb diameter for any of the planting dates (Table 4). Elephant clove weight was larger the first three dates and smaller the fourth date. Clove numbers for the Elephant variety were statistically highest for the mid-October and early-November dates and lowest for the early-October planted garlic, but clove numbers for the spring garlic were not significantly different than any of the other dates.

Among German White varieties planted at the Braker farm, bulb weights were highest in garlic planted in mid-September and early-October, second highest weights seen in mid-October and early-November, and the lowest weight in spring 2017 (Table 4). Average bulb diameter of German White was largest in mid-September; there were no significant differences in average bulb diameter for the other planting dates. German White clove weight was highest with the garlic planted the first three dates and lowest in spring 2017. There were no significant differences in clove number for German White except the smallest numbers amongst garlic planted in spring 2017.

For the Inchelium Red garlic planted at the Braker location, bulb weight was similar at all planting dates except for spring 2017 which were smaller (Table 4). Average bulb diameter was largest for garlic planted on the earliest date and smallest at the last planting date. The garlic planted in mid-October was similar in size to the garlic planted in early-November, while no differences were seen in size for garlic planted in early-November and spring 2017. Inchelium Red clove weight followed a similar pattern as seen for average bulb diameter, with highest weight in early-October, second highest weights in mid-October and early-November, and lowest weights for the spring 2017 garlic. Clove numbers were the same for all dates. No data was able to be collected for Inchelium Red planted at Braker Farm in mid-September due to possible sample theft.

At the Darr Agriculture Farm research site, Elephant bulb weight was highest for the early-October planting, with the early-November planting the second highest weight, but no differences between the mid-October and spring 2017 dates (Table 5). The largest average bulb diameter occurred with the early-October and mid-October planting dates, followed by early-November, and the smallest diameter seen with garlic planted in spring 2017. Early-October garlic had the highest clove weight, with early-November having the second highest; mid-October and spring were smallest. No significant difference in clove number was seen for the Elephant garlic at any of the planting dates.

As Table 5 also shows, German White garlic planted at Darr in early-October had the highest bulb weight. Second highest weight was mid-September, followed by early-November and then the spring planting. Average bulb diameter for German White planted in mid-September, early-October and early-November was the same while garlic planted in spring 2017 had the lowest bulb diameter. Clove weight varied significantly with early-October being highest, followed by mid-September, early- November and lowest bulb weight in spring 2017. German White clove number was highest for garlic planted in mid-September, early-October and early-November, followed by spring 2017 garlic with the lowest number of cloves.

Inchelium Red garlic planted in early-October at the Darr location had the highest bulb weight, with garlic planted in mid-September at a lower weight but still statistically similar, followed by mid-October and early-November, and lowest weight was garlic planted in spring 2017 (Table 5). Highest average bulb diameter for Inchelium Red was garlic planted in mid-September and early-October, followed by early-November, and smallest mid-October and spring 2017. Clove weight for Inchelium Red was highest in garlic planted in mid-September and early-October, followed by mid-October and early-November; spring 2017 had the lowest clove weight. The highest clove number came from garlic planted in mid-September and mid-October; early-October and early-November were similar, and spring 2017 was the lowest number.

At both the Darr and Braker Farm locations, the Elephant garlic produced heavier and larger diameter bulbs and cloves at all planting dates (Table 6). This would be expected since the Elephant variety is genetically programmed to have larger bulbs at maturity than true garlic; in fact, one clove can weigh as much as an entire bulb of true garlic varieties (Boyhan et al., 2012). The German White variety generally produced the smallest bulbs and cloves while the Inchelium Red variety consistently produced the greatest number of cloves per plant (Table 6). The Elephant variety produced the lowest number at all planting dates, suggesting that the Elephant variety produced fewer, but larger cloves. Again, these data are consistent with the genetic capability of true garlic (Boyhan et al., 2012). Inchelium Red, being a soft neck variety, produces several layers of cloves that wrap around the bulb (McLaurin et al., 2015), with larger cloves on the outside of the bulb and smaller cloves in the interior (Figure 7).

The planting location (Darr vs. Braker) effect on garlic production varied among planting dates and garlic variety (Tables 7-9). Almost all data for the Elephant variety were larger (in bulb weight) for early-October garlic at the Braker farm but larger for the Darr farm garlic in mid-October, but the differences had disappeared by early-November (Table 7). Data for all the growth parameters were at times not different statistically, but the trend at both farms was smaller bulbs as the season progressed. These findings agree with the results of Rahim et al. (2003), Sultana et al. (1997) and Islam et al. (1998). They reported that in early-plantings, plants attained higher vegetative growth which possibly led to the development of the largest bulbs. Yields larger at one farm on one date but larger at the other farm at another date could also be because the crops were exposed to varying temperatures and moisture levels at the two sites (Volk, 2009). Table 2 shows average monthly temperatures at Braker and Darr farms, and while temperatures were often 1 to 2 degrees warmer at the Braker farm than Darr, overall temperatures were similar. Table 9 shows rainfall totals for both farms. In March when active growth of the garlic resumes, the Springfield location had two inches greater rainfall than the Braker farm. Rainfall totals were similar at both locations in April, May and June.

German White had a larger yield (bulb weight) at the Braker Farm compared to the Darr Farm when planted in mid-September, but the Darr Farm's German White had the larger yield in early-October (Table 8). This is not consistent with dates found in the Rahim et al. (2003) research; there, late plantings produced smaller bulbs and lower yields. They suggested that bulbs planted late in the season would not have a long enough period of proper temperatures to develop vegetative growth. The data in our study supports the premise that yield of German White may be higher when planted earlier in the season (Rahim et al. 2003, Sultana et al. 1997 and Islam et al. 1998).

Table 9 shows that Inchelium Red garlic planted in early-October tended to be larger than garlic planted on the other dates, and the smallest yield was with garlic planted in spring 2017. These findings agree with research conducted in Virginia (Bratsch, 2009). Bratsch concluded that garlic planted in early- to mid-October had higher yields than garlic planted later in the autumn. Early- to mid-October plantings allowed for good root growth and some advanced top growth; earlier planting dates led to too much tender top growth by winter; while a later date may not allow adequate root development (Bratsch, 2009).

## SUMMARY

In conclusion, we found that the first Elephant garlic we planted had the largest yield at the Darr Farm, while we found no difference in yield of Elephant planted at the Braker location during the fall. For German White garlic, yield was largest when planted in early October at the Darr farm, and largest when planted in mid-September and early-October at Braker Farm. Inchelium Red garlic at the Darr site had the largest yields from the first two plantings, while no difference was seen in Inchelium Red regardless of the date at the Braker location. Spring yields were smaller for all garlic varieties compared to fall planted garlic. The study was repeated in fall 2017 and spring 2018. That data was not available at the time this thesis was written.

Table 1. Monthly rainfall at both planting locations during 2016/2017

| Month | Oronogo Rainfall Inches | Springfield Rainfall Inches |
|---|---|---|
| | Mean | Mean |
| September | 2.98 | 3.89 |
| October | 5.25 | 3.8 |
| November | 0.87 | 2.32 |
| December | 0.59 | 0.62 |
| January | 3.65 | 4.07 |
| February | 0.34 | 0.39 |
| March | 2.7 | 4.79 |
| April | 11.24 | 12.03 |
| May | 8.0 | 7.42 |
| June | 4.8 | 4.99 |
| TOTAL | 40.42 | 44.32 |
| Average Monthly Rainfall | 4.04 | 4.43 |

Table 2. Monthly temperatures (°F) at both planting locations during 2016 and 2017

| Month | Oronogo Temperature $^0$F | | | Springfield Temperature $^0$F | | |
|---|---|---|---|---|---|---|
| | Max | Min | Mean | Max | Min | Mean |
| September | 83 | 62 | 72 | 84 | 62 | 73 |
| October | 76 | 55 | 65 | 76 | 54 | 65 |
| November | 64 | 43 | 53 | 62 | 40 | 51 |
| December | 46 | 26 | 36 | 45 | 26 | 35 |
| January | 49 | 29 | 39 | 49 | 28 | 39 |
| February | 61 | 37 | 49 | 60 | 35 | 47 |
| March | 63 | 42 | 53 | 62 | 40 | 51 |
| April | 70 | 50 | 60 | 70 | 49 | 60 |
| May | 78 | 55 | 67 | 76 | 54 | 65 |
| June | 86 | 64 | 75 | 84 | 63 | 73 |
| Average Mean | | | 56.9 | | | 55.9 |

Table 3. General Linear Model Univariate ANOVA Test for interactions between main factors for 2016/2017 garlic data.

| Growth Medium | Bulb Weight (g) | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| Location x Planting Date | *** | NS | *** | *** |
| Location x Variety | *** | NS | ** | NS |
| Planting Date x Variety | NS | *** | NS | * |
| Location x Planting Date x Variety | *** | *** | *** | *** |

NS = not significant at $p \leq 0.05$
* significant at $0.05 \geq p \geq 0.01$
** significant at $0.01 \geq p \geq 0.001$
*** significant at $0.01 \geq p \geq 0.001$

Table 4. Effect of planting data on garlic growth parameters, within variety, at the Braker Farm.

| Planting Date Effect On Garlic Growth | Bulb Weight (g)$^z$ | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| | Elephant | | | |
| Mid-September 2016 | -----$^y$ | ----- | ----- | ----- |
| Early- October 2016 | 212.3 b | 8.7 a | 204.0 a | 5.2 b |
| Mid-October 2016 | 215.5 b | 8.6 a | 208.6 a | 5.9 a |
| Early- November 2016 | 226.5 b | 8.8 a | 212.8 a | 5.9 a |
| Spring 2017 | 178.4 a | 8.2 a | 152.5 b | 5.4 ab |
| | German White | | | |
| Mid-September 2016 | 118.0 a | 7.0 a | 108.6 a | 8.9 a |
| Early- October 2016 | 109.7 a | 6.8 bc | 97.7 b | 9.8 a |
| Mid-October 2016 | 99.2 b | 6.4 c | 88.1 c | 8.9 a |
| Early- November 2016 | 95.5 b | 6.7 c | 85.8 c | 9.5 a |
| Spring 2017 | 60.6 c | 5.5 c | 56.5 d | 7.5 b |
| | Inchelium Red | | | |
| Mid-September 2016 | ----- | ----- | ----- | ----- |
| Early- October 2016 | 134.9 a | 7.8 a | 122.6 a | 17.5 a |
| Mid-October 2016 | 104.7 a | 6.8 b | 97.7 b | 17.1 a |
| Early- November 2016 | 99.2 a | 6.6 bc | 89.7 b | 15.8 a |
| Spring 2017 | 74.7 b | 6.3 c | 64.4 c | 22.5 a |

$^z$ mean separation by planting date within individual Variety sections by Duncan; means followed by same letter are not statistically significant at alpha = 0.05. (Insufficient data available for mean separation in blank spaces).
$^y$ dashed lines within table represent data that was incomplete and therefore, not analyzed nor included in the table.

Table 5. Effect of planting data on garlic growth parameters, within variety, at the Darr Center.

| Planting Date Effect On Garlic Growth | Bulb Weight (g)[z] | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| | Elephant | | | |
| Mid-September 2016 | -----[y] | ----- | ----- | ----- |
| Early- October 2016 | 237.0 a | 9.3 a | 227..7 a | 5.5 a |
| Mid-October 2016 | 167.8 c | 8.9 a | 158.3 c | 5.1 a |
| Early- November 2016 | 195.9 b | 8.3 b | 182.3 b | 5.5 a |
| Spring 2017 | 167.9 c | 7.7 c | 158.3 c | 5.1 a |
| | German White | | | |
| Mid-September 2016 | 106.3 b | 6.8 a | 98.3 b | 11.3 a |
| Early- October 2016 | 125.8 a | 7.0 a | 117.6 a | 11.2 a |
| Mid-October 2016 | ----- | ----- | ----- | ----- |
| Early- November 2016 | 93.8 c | 6.6 a | 84.7 c | 11.2 a |
| Spring 2017 | 63.2 d | 5.5 b | 56.1 d | 6.7 b |
| | Inchelium Red | | | |
| Mid-September 2016 | 129.5 a | 7.7 a | 119.9 a | 21.7 a |
| Early- October 2016 | 137.9 a | 7.9 a | 124.3 a | 19.6 ab |
| Mid-October 2016 | 100.0 b | 6.3 c | 91.5 b | 22.4 a |
| Early- November 2016 | 104.0 b | 7.2 b | 95.0 b | 18.4 ab |
| Spring 2017 | 88.8 c | 6.5 c | 78.1 c | 13.7 b |

[z] mean separation by planting date within individual Variety sections by Duncan; means followed by same letter are not statistically significant at alpha = 0.05. (Insufficient data available for mean separation in blank spaces). [y] dashed lines within table represent data that was incomplete and therefore, not analyzed nor included in the table.

Table 6. Effect of variety on garlic growth parameters, within planting date at the Darr Center.

| Variety Effect on Garlic Growth | Bulb Weight (g)[z] | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| | Mid-September 2016 planting date[y] | | | |
| Elephant | ----- | ----- | ----- | ----- |
| German White | 106.3 b | 6.8 b | 98.3 b | 11.3 b |
| Inchelium Red | 129.5 a | 7.7 a | 119.9 a | 21.7 a |
| | Early- October 2016 planting date | | | |
| Elephant | 237.0 a | 9.3 a | 227.7 a | 5.5 c |
| German White | 125.8 c | 7.0 c | 117.6 b | 11.2 b |
| Inchelium Red | 137..9 b | 7.9 b | 124.3 b | 19.6 a |
| | Mid October 2016 planting date[y] | | | |
| Elephant | 167.8 a | 8.9 a | 158.3 a | 5.1 b |
| German White | ----- | ----- | ----- | ----- |
| Inchelium Red | 100.0 b | 6.3 b | 91.5 b | 22.4 a |
| | Early- November 2016 planting date | | | |
| Elephant | 195.9 a | 8.3 a | 182.3 a | 5.3 c |
| German White | 93.8 b | 6.6 c | 84.7 b | 11.2 b |
| Inchelium Red | 104.0 b | 7.2 b | 95.0 b | 18.4 a |
| | Spring 2017 planting date | | | |
| Elephant | 167.9 a | 7.7 a | 158.3 a | 5.1 b |
| German White | 63.2 c | 5.5 c | 56.1 c | 6.7 b |
| Inchelium Red | 88.8 b | 6.5 b | 78.1 b | 13.7 a |

[z] mean separation by variety within individual Planting Date/Location sections by Duncan; means followed by same letter are not statistically significant at alpha = 0.05. [y] mean separation by location within individual Planting Date/Location sections by ANOVA F-test; means followed by same letter are not statistically significant at alpha = 0.05. (Insufficient data available for mean separation in blank spaces)

Table 7. Effect of planting location on garlic growth parameters, within planting date, for the garlic variety, 'Elephant'.

| Variety Effect on Garlic Growth | Bulb Weight (g)[z] | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| | September 2016 | | | |
| Braker Farm | -----[y] | ----- | ----- | ----- |
| Darr Center | ----- | ----- | ----- | ----- |
| | Early- October 2016 planting date | | | |
| Braker Farm | 212.3 b | 8.7 b | 204.0 b | 5.2 a |
| Darr Center | 237.0 a | 9.3 a | 227.7 a | 5.5 a |
| | Mid-October 2016 planting date | | | |
| Braker Farm | 215.5 a | 8.6 a | 208.6 a | 5.9 a |
| Darr Center | 167.8 b | 8.9 a | 158.3 b | 5.1 b |
| | Early- November 2016 planting date | | | |
| Braker Farm | 226.9 a | 8.8 a | 212.8 a | 5.9 a |
| Darr Center | 195.9 a | 8.3 a | 182.3 a | 5.5 a |
| | Spring 2017 planting date | | | |
| Braker Farm | 178.4 a | 8.2 a | 162.5 a | 5.4 a |
| Darr Center | 167.9 a | 7.7 a | 158.3 a | 5.1 a |

[z] mean separation by location within individual Planting Date sections by ANOVA F-test; means followed by same letter are not statistically significant at alpha = 0.05.
[y] dashed lines within table represent data that was incomplete and therefore, not analyzed nor included in the table.

Table 8. Effect of planting location on garlic growth parameters, within planting date, for the garlic variety, 'German White'.

| Variety Effect on Garlic Growth | Bulb Weight (g)[z] | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| | Mid-September 2016 planting date | | | |
| Braker Farm | 118.0 a | 7.0 a | 108.6 a | 9.5 b |
| Darr Center | 106.3 b | 6.8 a | 98.3 a | 11.3 a |
| | Early- October 2016 planting date | | | |
| Braker Farm | 109.7 b | 6.8 a | 97.7 b | 8.9 b |
| Darr Center | 125.8 a | 7.0 a | 117.6 a | 11.2 a |
| | Mid-October 2016 planting date | | | |
| Braker Farm | -----[y] | ----- | ----- | ----- |
| Darr Center | ----- | ----- | ----- | ----- |
| | Early- November 2016 planting date | | | |
| Braker Farm | 95.5 a | 6.7 a | 85.8 a | 8.9 b |
| Darr Center | 93.8 a | 6.6 a | 84.7 a | 11.2 a |
| | Spring 2017 planting date | | | |
| Braker Farm | 60.6 a | 5.5 a | 56.5 a | 7.5 a |
| Darr Center | 63.2 a | 5.5 a | 56.1 a | 6.7 a |

[z] mean separation by location within individual Planting Date sections by ANOVA F-test; means followed by same letter are not statistically significant at alpha = 0.05.
[y] dashed lines within table represent data that was incomplete and therefore, not analyzed nor included in the table.

Table 9. Effect of planting location on garlic growth parameters, within planting date, for the garlic variety, 'Inchelium Red'.

| Variety Effect on Garlic Growth | Bulb Weight (g)[z] | Average Bulb Diameter (cm) | Clove Weight (g) | Clove Number |
|---|---|---|---|---|
| | Mid-September 2016 planting date | | | |
| Braker Farm | -----[y] | ----- | ----- | ----- |
| Darr Center | ----- | ----- | ----- | ----- |
| | Early- October 2016 planting date | | | |
| Braker Farm | 134.9 a | 7.8 a | 122.6 a | 17.5 a |
| Darr Center | 137.9 a | 7.9 a | 124.3 a | 19.6 a |
| | Mid October 2016 planting date | | | |
| Braker Farm | 104.7 a | 6.8 a | 97.7 a | 17.1 a |
| Darr Center | 100.0 a | 6.3 b | 91.5 a | 22.4 a |
| | Early- November 2016 planting date | | | |
| Braker Farm | 99.2 a | 6.6 b | 89.7 a | 15.8 a |
| Darr Center | 104.0 a | 7.1 a | 95.0 a | 18.4 a |
| | Spring 2017 planting date | | | |
| Braker Farm | 74.7 b | 6.3 a | 64.4 b | 22.5 a |
| Darr Center | 88.8 a | 6.5 a | 78.1 a | 13.7 b |

[z] mean separation by location within individual Planting Date sections by ANOVA F-test; means followed by same letter are not statistically significant at alpha = 0.05.
[y] dashed lines within table represent data that was incomplete and therefore, not analyzed nor included in the table.

Figure 1. German White garlic bulb cut open to show the arrangement and size of cloves.

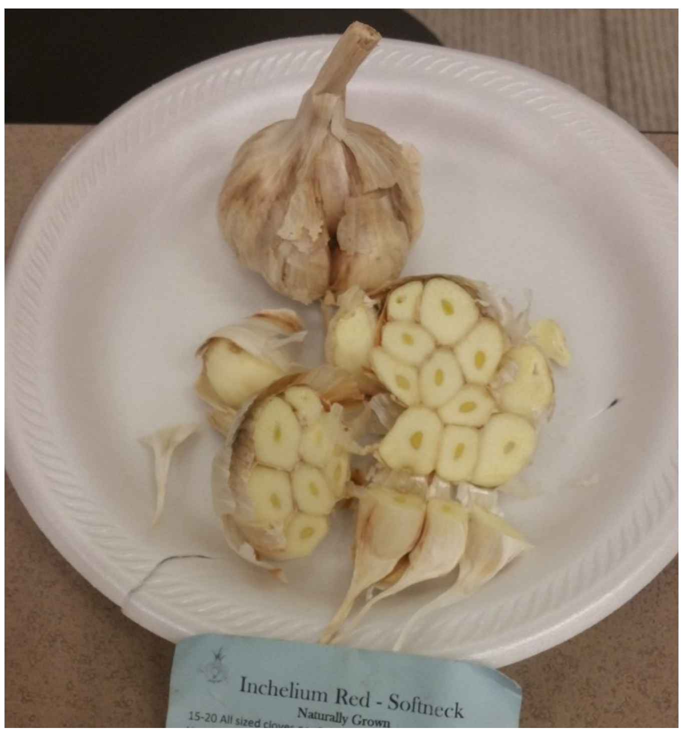


Figure 2. Inchelium Red garlic bulb cut open to show arrangement and size of the cloves.


Figure 3. Granulated Fertilizer used in raised beds.

Figure 4. Tractor with three in one attachment

Figure 5. Darr Agricultural Center farm beds.

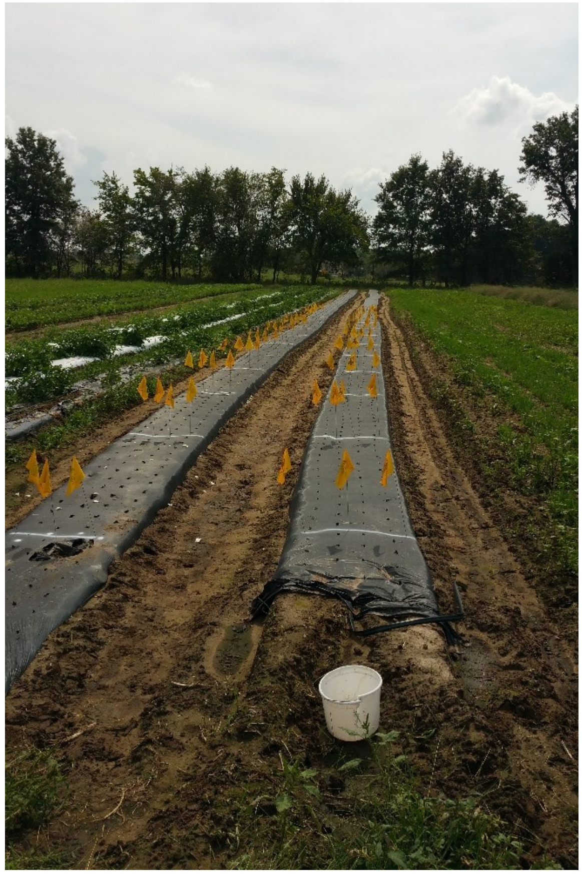

Figure 6. Braker farm beds.

Figure 7. Handmade tool created to pop holes in plastic and soil.

Figure 8. Inchelium shortly after harvest.

Figure 9. German shortly after harvest.


Figure 10. Elephant garlic cut open to show orientation and size of cloves within the bulb.

Figure 11. Elephant garlic soon after harvest.


Figure 12. Liquid fertilizer used in the spring.

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