PUMPKIN PRODUCTION SYSTEMS: UNDERSTANDING SUPPLEMENTAL NITROGEN NEEDS AND INCREASING PROFITABILITY THROUGH BLACK PLASTIC MULCH AND TRANSPLANTS

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Master of Science

by
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ABSTRACT

The goals of the studies presented in this thesis were to maximize profitability for pumpkin growers by testing new cropping systems and ensuring efficient use of nitrogen fertilizer and to better understand nitrogen needs in pumpkin production. Current nitrogen recommendations and application methods were tested and cropping systems using black plastic mulch and transplants were examined. Added nitrogen showed no effect on marketable yield in both years of the study. Changes in application timing through fertigation showed no effects on yield. In the cropping systems study economic analysis was conducted; direct seed into plastic mulch, transplant into bare ground, and transplant into plastic mulch were found to increase profits by 41%, 44%, and 34% per hectare, respectively when compared to direct seed into bare ground. Use of transplants significantly increased fruit number in three of four planting dates, presence of mulch also increased fruit number in three of four plantings.

BIOGRAPHICAL SKETCH

Sarah Hulick grew up on a small farm in Greenville, NY where she became intrigued by agriculture and how plants grow. She attended Cornell University for her undergraduate education and studied plant science and agricultural sciences with a concentration in education and communications. Her love of scientific inquiry and applied research evolved throughout her undergraduate career through many experiences, but importantly: a summer internship with the Cornell Vegetable Team through Cornell Cooperative Extension, an independent research project while studying Ecology and Conservation in Costa Rica, and working as a research assistant in Dr. Anu Rangarajan's reduced tillage and vegetable culture research program.

Sarah conducted her thesis research on economically and environmentally sustainable pumpkin production with Dr. Stephen Reiners and Dr. Hans Christian (Chris) Wein in the Department of Horticulture and Dr. Bradley Rickard in the Dyson School of Applied Economics and Management at Cornell University. Sarah believes the point where social and life sciences meet is the place where research can most often help people, and is glad to have been able to complete a project that can have real world impacts for farms and the environment. Sarah does not currently have long term future plans, but hopes to find a way to combine her passions of horticulture, education, and travel in a way that will help and feed people.

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"No one who achieves success does so without the help of others."

– Alfred North Whitehead

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CHAPTER 1

Literature Review:

Introduction

Jack-o'-lantern pumpkins are a major crop in New York State, worth an average of $30 million annually and grown on over 2,500 hectares (ha) (USDA, 2013). Pumpkin market value in 2012 was worth over $145 million dollars annually in the USA (USDA, 2013). Pumpkins are planted on over 32,000 hectares (USDA, 2009).

As the cost of pumpkin production has increased due to increased hybrid seed costs and greater use of expensive fungicides, growers are interested in increasing their yield per unit area. In New York State, few growers use transplants as their current method of stand establishment. However, as seed costs increase, more growers are choosing this method in order to gain the best stand from the least seed. To achieve comparable plant stands, direct seeding usually takes at least twice as many seeds as using transplants due to germination and establishment issues. Information on using transplants in pumpkin productions systems is needed to ensure growers have the knowledge to make educated, research based, decisions for their farm business.

Plastic mulch is common in production of many other vegetable crops in New York including tomatoes, peppers, and melons, but it not widely used in pumpkin plantings. Many of the same benefits that these crops gain from plastic mulch, including increased yields, reduced evaporation and weed control, could potentially be gained in pumpkin production. It is thought that within the cucurbit family, different species will react similarly to season extension techniques but little research has been conducted on *Cucurbita pepo*.

Nitrogen (N) fertilizer holds the key to a successful crop for many growers and is also a significant production cost. Nitrogen is known to be the limiting nutrient factor for many vegetable crops. As fertilizer costs have increased producers have been questioning the current recommendations and how to be most efficient with added N. Understanding how much nitrogen pumpkins need and when and how to apply it will improve economic and environmental sustainability of pumpkin production.

Much of the growth in pumpkin production has been driven by the growing popularity of Halloween (Hsu, 2012). Many pumpkins are grown solely for Halloween sales and are used for decoration rather than for human consumption. Timing is everything for the decorative market, with consumer demand for fruit only occurring from September 1st through October 31st. Consumers now demand multiple pumpkins per family and related fall agro tourism activities have spurred the number and value of pumpkins being produced over the last 30 years.

Nitrogen

Nitrogen is a critical nutrient in vegetable production. Availability of nitrogen (N) is often the most limiting nutrient for cucurbit production. Management guides often suggest pumpkins need a total of 134-146 kilograms (kg)/hectare (ha) or $kg \cdot ha^{-1}$ of nitrogen. (Riggs, 2003) A healthy soil with active microorganisms, adequate moisture, and a stable, slightly acidic pH will provide approximately 7-15 kg of N for each percent of organic matter present. When factoring in N gained from mineralization usually between 89-112 $kg \cdot ha^{-1}$ is needed to fulfill pumpkin crop requirements. (Riggs, 2003) This information can be widely found in many management handbooks and extension publications, but is rarely tested and anecdotally assumed to be correct. One objective of this thesis research was to determine if this golden rule of pumpkin nutrient management would hold true upon field trial replication. With fertilizer input costs constantly rising and growing concerns about the environmental degradation caused by N leaching, understanding the N needs of pumpkins is becoming more important.

Increased nitrogen fertilization has a general affect of increasing yield in cucurbits, at least until an upper limit is reached. Dweikat and Kostewicz (1989) found that yield of zucchini squash increased as added N rates increased from 67 $kg \cdot ha^{-1}$ to 202 $kg \cdot ha^{-1}$ in Florida, but yield decreased when N rates went above 202 $kg \cdot ha^{-1}$. Also in Florida, Brinen (1979) found similar results in watermelon at equally high N rates. An upper limit of N was found in a study by Swaider (1985) where above optimal levels of added N caused a decrease in overall yield along with excessive vine growth and a delay in fruit set. Another Swaider (et al., 1994) study showed the highest yields in a N and potassium study on pumpkins were found at 112 $kg \cdot ha^{-1}$ of N. Yield increases that were found were due to an increase in marketable fruit number, rather than changes in fruit size. The highest N rates in the study, at 168 $kg \cdot ha^{-1}$ and 196 $kg \cdot ha^{-1}$, caused delay in fruit set and an increase in unmarketable, green fruit at harvest. Even at these high N rates, none of the treatments were found to have excessive vegetative growth.

A study was conducted in the cooler mountain regions of North Carolina to determine the most useful N rates for pumpkin production on highly erodible and drought susceptible soils. Pumpkins in this no till system were found to have the greatest total yield and number of fruit with the highest N fertilization rate in the study, 120 $kg \cdot ha^{-1}$ (Harrelson et al., 2008). The study was conducted across three separate locations with varying precipitation and elevation. Harrelson felt further study should examine whether yields would continue to increase with increasingly higher N applications. This study also found that at later planting dates (July 8) using the highest N rate produced similar yields as a normal planting date with a lower N application. The highest N rate used in this study is quite similar to standard grower practice for New York and Northeast growers.

A Florida study looking at nitrogen rates in summer squash where production systems were treated with 0-336 $kg \cdot ha^{-1}$, a sharp increase in yield occurred between the 56 $kg \cdot ha^{-1}$ and 112 $kg \cdot ha^{-1}$ treatments and then plateaued as N rates increased (Santos et al., 2006). In another location in that study, yield stopped responding to increases to N above the 56 $kg \cdot ha^{-1}$ treatment, most likely due to nutrient rich soils. In both locations the vegetative vine vigor continued to increase as N increased, but did not negatively affect fruit yields. Many vegetable production fields are very nutrient rich, and may stop responding to added N at lower rates than expected. In a Reiners and Riggs (1997) study in New York, there is also no response of pumpkin yield to increasing rates of nitrogen.

Nitrogen rates of 67, 112, and 157 kg·ha^{-1} were added to different plant densities and vining and semi bush varieties of jack-o'-lantern pumpkins. Contrary to a previous pumpkin study, (Swaider et al., 1994) they did not find that the highest N yields resulted in delayed harvest or significantly more green, cull fruit at harvest. Conclusions were that they might need better water optimization to truly see the effects of excess N on the production systems. A 2010 study in Ontario, Canada on N budgets in butternut squash showed that 7 out of 11 sites were unresponsive to any added N (Van Eerd, 2010). For the sites that did respond to N the most economical rate of N was between 105 and 129 kg·ha^{-1}.

Nitrogen treatments had little or no effect on machine harvested cucumbers in Ontario, Canada (Van Eerd and O'Reilly, 2009). The treatments ranged from 0 to 220 kg·ha^{-1} of nitrogen; marketable cucumber yield did not respond to N application and yields were not significantly different than the control of 0 N added. In Ontario, Canada, the recommended rate of N suggested to growers is a split application of 110 kg·ha^{-1}. This study found no need to add nitrogen or split applications to the generally productive, nutrient rich, and nonresponsive soils in the region. The authors concluded 0-30 kg·ha^{-1} might be more appropriate N rate for the region and short season crop. Another study looking at nutrient management effects on quality and yield in pickling cucumbers found that in both tested varieties, yield only increased up to 134 kg·ha^{-1} of N, at which point it plateaued (Johnson et al., 2013). Tested nitrogen treatments included those up to 224 kg·ha^{-1}. Many quality problems for processing occurred at the higher treatment rates.

In can be concluded from the literature that most cucurbits, including studies specifically looking at *Cucurbita pepo* have determined that yield does not increase linearly with added N. Yield increases with nitrogen added until physiological needs are met, found between 56 $kg\cdot ha^{-1}$ to 134 $kg\cdot ha^{-1}$ (Reiners and Riggs, 1997; Santos et al. 2006; Johnson et al., 2013; Swaider et al., 1994) A detriment to yield or quality was found at levels over 150 $kg\cdot ha^{-1}$ in multiple experiments (Dweikat and Kostewicz,1989; Johnson et al., 2013; Swaider et al., 1994).

Too little N can result in reduced yield and fruit size, but excess N can delay flowering and cause high amounts of green, unmarketable fruit at harvest (Swaider et al., 1994). Finding the proper amount of N that pumpkins need is important to increasing yield per unit area and unit of inputs. In Illinois, nitrogen fertilizer requirements were studied in *Cucurbita moschata* in relation to differing cropping systems and N inputs (Swaider and Shoemaker, 2004). N fertilizer rates were applied at 0, 56, 112, 168, 224 $kg\cdot ha^{-1}$ on four cropping systems: pumpkins following fallow ground, pumpkin following soybeans, pumpkin following one and two years maize. Averaged over the two years of the study pumpkins following fallow ground had the highest total weight of ripe fruit when 128 $kg\cdot ha^{-1}$ of N was applied. Pumpkins following soybean had similar yields with 109 $kg\cdot ha^{-1}$ of N added demonstrating that soybeans created a 19 $kg\cdot ha^{-1}$ credit of N. Following corn, pumpkins needed more N to reach highest yields of 151 $kg\cdot ha^{-1}$ and 179 $kg\cdot ha^{-1}$ for two years of maize, respectively. Negative effects from excessive N fertilizer were greater in pumpkins following soybean compared to pumpkins following two years of maize, which decreased total yield anywhere between 3% - 21%. A critical level for preplant soil N, identified as the point beyond which there was little or no yield response to added N, was 17.6 mg/kg (Swaider and Shoemaker, 2004).

Drip irrigation systems can deliver smaller volumes of water as needed, thus reducing water application compared to other popular irrigation options such as overhead and furrow. Application of fertilizer through irrigation sources is known as fertigation. It has the benefits of lowering fertilizer inputs, reducing nutrient leaching, and ability to "spoon feed" crops to meet more time specific nutrient demands. Because of the dynamic state of plant available nitrogen in agricultural systems it is important yet difficult to optimize fertilizer applications for amount and timing. Fertigation can be very useful for applying accurate and timely nitrogen during early fruit development when the plants needs are the highest (Swaider, 1985; Swaider et al. 1994). One challenge in designing a fertility program for pumpkins is their vine growth. Typically, all nitrogen treatments must be applied prior to the time when "vines run", the period when plants produce large vines. Fertigation has the added benefit of allowing growers to fertilize even after vines run, which would be impossible with a traditional sidedressing of granular or liquid fertilizer.

Although the Mid Atlantic and Northeast states, where most horticultural pumpkin production occurs, have sufficient rainfall accumulation for cucurbit production, the timing of these rain events is becoming more volatile (DeGaetano, 2011). Plant stress from drought conditions, for at least part of the growing season, is becoming more frequent. As climate change continues to affect the regions weather patterns, it will become increasingly more important to have irrigation available to crops, in order to sustain productivity during dry periods between natural rain events. With an increase in hectares that have irrigation available, fertilization opportunities increase to include fertigation as an option for more growers. It is important to improve scientific understanding of how fertigation can affect pumpkin production.

A Swaider et al. (1994) study found that fertigated pumpkin production on sandy soils in Illinois, required much less N and potassium (K) input for maximum yield when compared to traditional dry-blend fertilizer, respectively 116 $kg \cdot ha^{-1}$ compared to 196 $kg \cdot ha^{-1}$ of N. The highest dry blend application, which was 196N-280K $kg \cdot ha^{-1}$ decreased yields significantly. Total marketable yields were highest at the 112N-112K or 112N-224K fertigation treatments.

Methods of fertilizer application and nitrogen fertigation were studied in squash to determine effects of yield and nutrient content in Irbid, Jordan (Mohammad, 2004). N was added at 0, 50, 100, and 150 mg 1^{-3} N concentration in irrigation water, and a soil application that is equivalent to the 100 mg fertigation application. Compared to the control of N=0, shoot dry matter and yield were increased by all treatments. Total yield was similar for all fertigation treatments in the first year of the study, but with significantly more and smaller fruit for the highest two N rates. Soil application gave a lower yield than the equivalent fertigation treatment suggesting a comparative advantage of fertigation. Positive effects of fertigation have been reported on yields in several vegetable crops (Clough et al., 1990, 1992; Mohammad et al. 1999). The lowest fertigation rate was adequate to obtain the highest yields in year one of the study, but needed a higher rate in year two (Mohammad, 2004).

Season Extension

Many large size jack-o'-lantern pumpkins have long field seasons; they need over 110 days to reach maturity. To ensure a pumpkin crop by mid September, when the market for Halloween and autumn agro tourism activities is in full swing, growers would need to plant these long season varieties in May. In Upstate New York many locations still run the risk of frost until mid to late May, which does not give the soil adequate time to reach 21 degrees Celsius for optimum germination of cucurbits (Riggs, 2003). Season extension techniques, such as those tested in this research, including black plastic mulch and transplanting for stand establishment can help growers get a jump start on the season and wait until early to mid June to plant. At this point, soils have reached ideal growing temperatures and the threat of frosts is over.

Plastic Mulch

Plastic mulch can provide many benefits to cucurbit production. Plastic mulch can modify soil temperature, conserve soil moisture by reducing evaporation, reflect radiant energy into the plant canopy, increase the air temperature microclimate around the plant, control weeds, and maintain good soil structure (Oebker and Hopen, 1974). Plastic mulch raises soil temperatures in the spring, which can promote quick root development and early growth in crops grown on plastic. Bonanno and Lamont (1987) also determined that using plastic mulch decreases fertilizer leaching. Plastic mulch can decrease erosion when positioned properly across the gradient in a field. When used in common plant spacing, usually 50% or more of the soil surface is covered and protected from raindrop velocity, thus reducing soil particle detachment (Midwest Plan Service, 1992). Plastic mulch is best known for increasing maturation rate but has also been shown to increase total yields in many vegetable crops including cucurbits, melons, peppers, tomatoes, and cole crops. Although most of the work in cucurbits has not been conducted on *Cucurbita pepo* it is thought different species will have similar reactions and benefits.

The origin of plastic mulch sheeting use in horticulture dates back to the 1950's when Emmert (1957) began experimenting with using it as ground mulch in vegetable cropping systems along with row covers, and as an alternative to glass for greenhouses. Since this time the use of black plastic polyethylene mulch in horticulture has continually increased. In 1999, over 30 million hectares were covered in plastic mulch in the USA; the figure has risen since then (Kasirajan and Ngouajio, 2012; Miles et al. 2005). The world consumption of low density polyethylene mulching films for horticulture was at 700,000 tons/year in 2006 (Espi et al., 2006). The practice of using plastic mulch has become the common practice for the following vegetable crops; bell pepper (*Capsicum annuum*), cucumber (*Cucumis sativus*), eggplant (*Solanum melongena*), muskmelon (*Cucumis melo*), summer squash (*Cucurbita pepo*), tomato (*Solanum lycopersicum*), and watermelon (*Citrullis lanatus*) (Kasirajan and Ngouajio, 2012).

Plastic mulch is an important cornerstone increasingly used in intensive vegetable cropping systems. Plastic mulch allows drip irrigation to be used most efficiently, which maximizes advantages that can be gained from decreased water evaporation. Irrigation requirements are greatly lowered when plastic mulch and drip irrigation are used in conjunction (Hanlon and Hochmuth, 1989). Used in conjunction with drip irrigation plastic mulch can decrease irrigation needs by up to 47% when compared to traditional overhead sprinklers (Clough et al., 1987; Jones et al., 1977).

Black plastic mulch and supplemental irrigation were found to have a synergistic effect of fruit yield for acorn squash (*Cucurbita pepo* L var. *pepo*) in a 1994, Colorado study by Ells et al.. The study was designed to assess root proliferation across many treatments of full, half, or no supplemented irrigation across bare ground and plastic mulch. Although significant changes in patterns of root development were not found between type of irrigation and mulch presence, yield showed differences between treatments. Squash grown on plastic, yielded 35% more on average, than squash grown on bare ground. The combination of black plastic mulch and full irrigation of either trickle or furrow produced the highest yields in all three years of the study. Another interesting discovery was that yields were similar between plastic mulch treatments that received 50% of water requirements and bare ground treatments that received full water requirements, suggesting decreased evaporative water loss in mulched plots. In the final year of the study, yields were significantly lower in the bare ground treatments receiving 50% and 0 irrigation, as compared to all the mulched plots and the bare ground treatment receiving full irrigation. Especially when combined with irrigation, black plastic is viable way to increase yields in cucurbit systems.

Black polyethylene mulch is the most commonly used mulch in conventional cucurbit cropping systems (Lamont, 1993; Riggs, 2003). In a study looking at drought conditions in acorn squash, yield and fruit number were higher in treatments under plastic (Ells et al., 1994). A study in Mexico looking at the effects of plastic soil mulching and row covers on zucchini and watermelon found that the plastic mulch without row cover treatments induced the greatest yield benefits (Ibarra Jimenez and Flores Velasquez, 1997). Increased yields were very significant at 208% for ‘Charleston Gray’ watermelon compared to the untreated control. ‘Grey Zucchini’ yield increased 177% compared to the control; days to harvest were decreased for both crops. Ibarra Jimenez (et al. 2005) conducted another study with watermelon looking at multiple types of soil mulch covers and row covers and that study also found that the highest marketable and total yields were found in the clear plastic mulch and black plastic mulch treatments. These were also the most economical treatments making the technology that much more applicable for growers.

A study in Mexico looking at early and total yield of cucumbers grown on black plastic mulch or a combination of mulch and row cover showed a significant increase in early yield between an untreated control and cucumbers grown on black plastic, but the total yields were not significantly different (Ibarra Jimenez et al., 2004). The jack-o’-lantern pumpkin market in the USA is so influenced by Halloween that early yield is not a premium advantage like it is for seasonal fresh market vegetables. Total yield is a more important determining factor for pumpkin growers than early yield. Total yield is often positively affected by plastic mulch as well.

Field studies conducted in Florida found significant increase in tons/hectare and kg/fruit when comparing watermelons grown on mulched plots to those grown on bare soil treatments (Brinen, 1979). Yields increased from 59.1 t/ha to 65.1 t/ha on treatments grown on plastic mulch. Bonnano and Lamont (1987) compared the effect of plastic mulch, with or without the addition of row cover, on muskmelon production in 1984 and 1985. Early and total yields increased when using either black or clear plastic mulches as compared to the bare ground treatment. In the 1984 growing year, total marketable yield increased from 17.4 t/ha to 28.2 t/ha from bare ground to plastic mulch. In 1985, in the same study, no treatments produced any significant differences for yield or any comparisons. The air temperature in 1985 was above normal and this may have negated any soil warming benefits that the mulch covered plots would have received.

Research conducted in Maine may be more applicable when considering replicable results for some of the areas with the most valuable pumpkin production throughout the Northeast; benefits of plastic mulch were also found in this cooler climate. ‘Earliqueen’ muskmelon was grown on black plastic mulch and bare ground plots. Average yield of plastic treatments was 20.4 kg/plot as compared to only 9.9 kg/plot when plastic was not used (Handley et al., 1998). Percent of yield that was classified as early also increased with the black plastic treatments.

In 1993, Lamont summarized the role of plastic mulch in intensive vegetable production by saying, “although a variety of vegetables can be grown successfully using plastic mulches; muskmelons, honeydews, watermelons, squash, cucumbers… have shown significant increases in earliness, total yield, and quality”. Much of the research that has been conducted on the effects of plastic mulch on vegetable production has not focused on pumpkins, but many consistencies are found within the cucurbit family and it is interesting to see if pumpkin will react to plastic mulch in a similar fashion as other cucurbits.

Research has shown several warm season cucurbits benefit from black plastic mulch. Numerous studies have reported benefits of black plastic mulch on cucurbit production, but information on *Cucurbita pepo* is limited (Brown and Osborn, 1989; Emmert, 1957; Loy and Bushnell, 1984; Loy and Wells, 1988). A study conducted in

Alabama looked at the effects of black plastic on a direct seeded and transplanted summer squash (Brown et al., 1996). Planting method had a significant effect on crop yield. Transplants produced 51% more fruit weight than the direct seeded plants. Direct seeded plants performed less well than transplanted plants, regardless of plastic mulch and row cover treatments. Presence or absence of black plastic mulch did not affect squash yields in this study. Transplants proved to be the most effective method for increasing squash yield in this study (Brown et al., 1996).

Transplants

Fruit yield is affected by stand establishment method. A survey of the research shows that transplants consistently accelerate maturation and produce higher yields when compared to direct seeding (Hall, 1989; NeSmith, 1993; Rulevich et al., 2003).
The use of transplants has been providing earlier harvests, better root system development, and the ability to grow warm season crops in cooler climates where direct seeding would be impossible since 1929 (NeSmith, 1999; Watts, 1929). Transplants have since been used for other benefits as well including: ability to manipulate planting time, increase crop uniformity, more efficient use of expensive hybrid seed, and utilization of other cultural practices such as plastic mulches, trickle irrigation, or row covers (Liptay et al., 1982; NeSmith, 1994,1997; Norton, 1968; Orzolek, 1991, 1996).

In 1968, Norton compared muskmelon, (*Cucumis melo* L.) grown in Alabama, three week old transplants to field seeded plots that were seeded the same day or 7-10 days earlier. Results showed significantly higher yields and fruit weight in the transplant plots as compared to the direct seeded plots. Two out of four years, transplants significantly increased yield in a Texas dry land irrigation and stand establishment study for *Cucumis melo* (Leskovar et al., 2001). *Cucurbita moshata* was studied to determine the affect of mulch and transplants on increasing early fruit set and total yield. Across very different growing seasons, transplants provided the most consistent method for improving both parameters (Rulevich et al. 2003).

Scientists have often questioned which physiological process is responsible for the increases in early and total yield that transplants induce. As early as 1973, Elstrom was theorizing that root proliferation was the cause of increased plant production.

Transplants quickly create a fibrous and extensive root system that is superior at nutrient sequestration when compared to the dominant taproot that direct seeding induces (Elmstron, 1973; Barber and Silverbush, 1984). The direct seeded tap root has its own benefits of anchoring the plant and being more resilient during times of drought, but in the absence of these conditions the root proliferation of transplants gives the added boost to produce significantly higher yields. NeSmith (1999) has also credited increased establishment and total yields in watermelon to the rapid root proliferation of transplanted melons.

Transplants can be grown in various size containers; research into the optimum cell size for yield has shown differing results. Hall (1989) showed an increase in total watermelon [*Citrullus lanatus* (Thunb.)] weight when increasing cell size from 18.8 cubic centimeters (cc) to 39.5 cc. In the Hall (1989) transplant study, yields were higher for transplanted watermelons than direct seeded plants for one of two varieties. In a watermelon transplant study conducted at the University of Florida, it was found that transplants grown in differing cell sizes between 18.8 cc and 65.5 cc had no effect on total yield or mean fruit weight (Vavrina et al., 1993).

Along with the size of the transplant another easily manipulated factor in transplant production is age of transplants. NeSmith compared plant growth and fruit yield in *Cucurbita pepo* (cultivar: summer squash) using transplants that were 10, 20, and 30 days old. Results indicated that 21 days old was the ideal time to field plant transplants (NeSmith, 1993). The study found that 10 days of delay after the original 21 worked well if weather delayed planting, but exceeding 31 days presented challenges for field planting. Transplants planted 28- 35 days after seeding showed slower growth when compared to those planted at 10, 14, or 21 days post seeding (NeSmith, 1993). Other work conducted on muskmelon and watermelon cucurbits found that transplant age did not have significant effects on fruit yield (NeSmith, 1993; Vavrina et al., 1993). Research suggests that transplants need to be old enough to withstand transportation and field handling, but young enough to not have excessive vine growth and root binding (NeSmith 1993, 1994; Vavrina et al., 1993). Twenty-one days seems to be an ideal for most cucurbits when the transplant falls into these physiological conditions.

Transplants, in many vegetable crops, have been known to decrease time from planting to fruit maturity (Hall, 1989; NeSmith, 1993; Rulevich et al., 2003). In jack-o'-lantern pumpkins, the ability to harvest sooner is of less concern than with most crops. Because jack-o'-lanterns are grown mainly for Halloween, there does not tend to be a monetary incentive for early season or late season fruit. In fact, the entirety of the marketable season usually falls September 1st through October 31st.

A study in Texas looked at six types of irrigations systems and the interaction with stand establishment on muskmelon (*Cucumis melo*) (Leskovar et al., 2001). The study, conducted over four growing seasons 1995-1998 has differing results based on the year. Some interesting observances were: direct seeded plants produced similar or higher total yields than transplanted counterparts in 2 of 4 years, which is in contrast to some other work (Hall, 1989). They found that direct seeded plants have greater yield potential in years where field conditions were close to optimal. In years without optimal growing conditions the yields in transplants were more than double that of direct seeded plants. Transplants responded to drip irrigation better than to furrow irrigation, but direct seeded plants performed best at 30 cm sub surface drip irrigation (Leskovar et al., 2001).

Cucurbits being sub-tropical in origin are not ideally suited to the cooler climate cucurbit production areas of the Northeast. Transplanting alone may not be enough to ensure increased yields and guarantee crop establishment. Orzolek (1991) discusses transplant establishment issues that occur for 5-14 days after transplanting when plants are highly susceptible to sunscald, sand blasting and evapotranspiration induced wilting due to high, constant winds and high temperatures. Low night temperature can also retard crop establishment and reduce the positive effects of using transplants. Additional cultural inputs can be used to reduce the negative effects of harsh environmental conditions that transplants face in the first two weeks after planting. In order to enable long season crop production in cooler climates Orzolek (1996) promotes the use of added inputs such as plastic mulch or row covers. In 1974, Oebker and Hopen introduced the concept of “microclimate modification” for vegetable crop ecosystems. The modification technique of using plastic mulch has been widely adapted in cucurbit production and is considered progressive influence on plant development (Oebker and Hopen, 1974).

Cost of Production

By reviewing the literature we find that season extension techniques such as black plastic mulch and transplants offer opportunities for increased yields. With these increased yields come increased input usage and input costs and more intensive agriculture. There are increased costs associated with direct materials such as: plastic mulch, trickle irrigation, transplant cell trays, and greenhouse space (Riggs, 2003). Furthermore, specialized equipment and labor costs can add significant cost increases. According to the Penn State Extension, the switch from no-till pumpkin production to plasticulture production will increase cost of production by $422.69 per hectare (Orzolek et al., 2012), an increase of 4%. Transplanting is not yet a commonly used practice in pumpkin production, and costs of transplant production are hard to find and infrequently documented. Transplanting is a common practice for other cucurbits; a 2006 budget estimated the costs of transplants to be $518.70 per hectare for cantaloupe production (Orzolek et al., 2006). Determining the changes in costs and revenues, and the production benefits of these season extension cropping systems is an important objective of this thesis research.

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CHAPTER 2

Supplemental Nitrogen and Application Method Has Little Effect on Marketable Yield in Jack-o'-lantern Pumpkins

Abstract:

Field studies were conducted at the New York State Agricultural Experiment Station in Geneva, NY in 2011 and 2012 to determine the affect of supplemental nitrogen and application method of nitrogen on pumpkin (Cucurbita pepo L.) marketable yield. Total yield (green fruit included) was affected by increasing N rates (0, 56, 112, 168 $kg \cdot ha^{-1}$), but marketable yield only showed a trend for increased yield at higher N rates. Fruit size and fruit number were unaffected by treatments. Two fertigation timing treatments were tested against a grower standard of split dry blend fertilizer application (all three at 112 $kg \cdot ha^{-1}$) and 0 $kg\ N \cdot ha^{-1}$. No differences were found in any yield components when comparing nitrogen application methods. The results suggest that pumpkins may not need as much supplemental nitrogen as currently recommended and in this production system fertigating showed no advantage over dry blend fertilizers.

Introduction:

Jack-o-lantern pumpkins are now worth an average of $30 million annually and planted on 2,500 hectares (ha) in New York State alone (USDA, 2013). On a nation wide scale, pumpkins have a market value of $145 million and are planted on 32,000 hectares (USDA, 2013; USDA, 2009). An increase in the popularity of Halloween over the past 30 years has driven the market for decorative pumpkins (Hsu, 2012). Consumers now demand multiple pumpkins per family and many pumpkin related fall attractions have caused the production and value to increase. As demand increases, input costs do as well. As fertilizer costs have increased producers have been questioning the current recommendations and how to be most efficient with added nitrogen (N). Understanding how much nitrogen pumpkins need and when and how to apply it will improve economic and environmental sustainability of pumpkin production.

Increased nitrogen fertilization has a general affect of increasing yield in cucurbits, at least until an upper limit is reached. Dweikat and Kostewicz (1989) found that yield of zucchini squash increased as added N rates increased from 67 $kg \cdot ha^{-1}$ to 202 $kg \cdot ha^{-1}$ in Florida, but yield decreased when N rates went above 202 $kg \cdot ha^{-1}$. Also in Florida, Brinen (1979) found similar results in watermelon at equally high N rates. In a study by Swaider (1985), above optimal levels of added N caused a decrease in overall yield along with excessive vine growth and a delay in fruit set. Another Swaider (et al., 1994) study showed the highest yields in a N and potassium study on pumpkins were found at 112 $kg \cdot ha^{-1}$ of N. Yield increases that were found were due to an increase in marketable fruit number, rather than changes in fruit size. The highest N rates in the study, at 168 $kg \cdot ha^{-1}$ and 196 $kg \cdot ha^{-1}$, caused delay in fruit set and an increase in unmarketable, green fruit at harvest.

Pumpkins in a no till system, in North Carolina, were found to have the greatest total yield and number of fruit with the highest N fertilization rate in the study, 120 $kg \cdot ha^{-1}$ (Harrelson et al., 2008). This study also found that at later planting dates (July 8) using the highest N rate produced similar yields as a normal planting date with a lower N application. In Florida, summer squash were treated with between 0-336 $kg \cdot ha^{-1}$ on N. A sharp increase in yield occurred between the 56 $kg \cdot ha^{-1}$ and 112 $kg \cdot ha^{-1}$ treatments and then plateaued as N rates increased (Santos et al., 2006). At another location in that study, yield stopped responding to increases to N above the 56 $kg \cdot ha^{-1}$ treatment, most likely due to nutrient rich soils. In both locations the vegetative vine vigor continued to increase as N increased, but did not negatively affect fruit yields.

Many vegetable production fields are very nutrient rich, and may stop responding to added N at lower rates than expected. An Ontario, Canada study on N budgets in butternut squash showed that 7 out of 11 sites were unresponsive to any added N (Van Eerd, 2010). For the sites that did respond to N the most economical rate of N was between 105 and 129 $kg \cdot ha^{-1}$. Nitrogen treatments had little or no effect on machine harvested cucumbers in Ontario, Canada (Van Eerd and O'Reilly, 2009). The treatments ranged from 0 to 220 $kg \cdot ha^{-1}$ of nitrogen; marketable cucumber yield did not respond to N, yields were not significantly different than the control of 0 N added. This study found no need to add nitrogen or split applications to the nutrient rich and nonresponsive soils in the region. The authors concluded 0-30 $kg \cdot ha^{-1}$ might be more appropriate N rate for the region and short season crop. In a Reiners and Riggs (1997) study in New York, there was also no response of pumpkin yield to increasing rates of nitrogen. Nitrogen rates of 67, 112, and 157 $kg \cdot ha^{-1}$ were tested and contrary to a previous pumpkin study (Swaider et al., 1994) they did not find that the highest N yields resulted in delayed harvest or significantly more green, cull fruit at harvest. The authors concluded the system might need irrigation to see the effects of excess N on the production.

Application of fertilizer through irrigation sources is known as fertigation. Positive effects of fertigation have been reported on yields in several vegetable crops (Clough et al., 1990, 1992; Mohammad et al. 1999). Fertigation can be very useful for applying accurate and timely nitrogen during early fruit development when the plants needs are the highest (Swaider, 1985; Swaider et al. 1994). Fertigated pumpkin production on sandy soils in Illinois, required less N and K input for maximum yield when compared to traditional dry-blend fertilizer, respectively 116 $kg \cdot ha^{-1}$ compared to 196 $kg \cdot ha^{-1}$ of N (Swaider et al., 1994). The highest dry blend application, which was 196N-280K $kg \cdot ha^{-1}$ decreased yields significantly. Total marketable yields were highest at the 112N fertigation treatments. A study accessing nitrogen fertigation added N at 0, 50, 100, and 150 parts per million (PPM) N concentration in irrigation water, and a soil dry blend application that was equivalent to the 100 PPM fertigation application (Mohammad, 2004). Total yield was similar for all fertigation treatments in the first year of the study, but with significantly more and smaller fruit for the highest two N rates. Soil application gave a lower yield than the equivalent fertigation treatment suggesting a comparative advantage of fertigation (Mohammad, 2004).

It can be concluded from the literature that most cucurbits, including studies specifically looking at *Cucurbita pepo* have determined that yield does not increase linearly with added N. Yield increases with nitrogen added until physiological needs are met, found between 56 $kg \cdot ha^{-1}$ to 134 $kg \cdot ha^{-1}$ (Reiners and Riggs, 1997; Santos et al. 2006; Swaider et al., 1994) A detriment to yield or quality was found at high levels over 150 $kg \cdot ha^{-1}$ in multiple experiments (Dweikat and Kostewicz, 1989; Swaider et al., 1994). Studies on fertigation have shown potential for needing fewer added fertilizers than with traditional dry blend application (Mohammad, 2004; Swaider et al., 1994). The objective of our research was to determine the amount of added nitrogen needed in pumpkin production and to determine whether timing of N applications through fertigations would cause changes in pumpkin yield.

Materials and Methods:

Experiments were conducted in Geneva, NY in 2011 and 2012 on a Lima silt loam (fine-loamy, mixed, mesic, Glossoboric Hapludalf). Plant spacing in both years and in all plots was 1.2 meters in-row by 2.1 meters between rows. In 2011, a rye cover crop was planted the previous fall and removed the following spring by cutting at ground level and removing the straw from the field. This was done in an attempt to reduce residual soil nitrogen. 'Gladiator', a large semi bush variety (Harris Seeds, Rochester, NY) was hand planted approximately 5 cm from the banded fertilizer on June 15th. Three seeds were planted at each hill and thinned to one plant after germination.

Pre-season soil tests were conducted each year and the soils were found to be in the medium to high range for all tested nutrients. In 2011, phosphorus and potassium were banded at rates of 46.5 and 39.6 $kg \cdot ha^{-1}$ respectively, according to the soil test. Soil pH was in the 6.3 to 6.7 range in all fields, optimum for pumpkin production so no additional limestone was needed. Nitrogen treatments for the trial included season totals of 0, 56, 112, and 168 $kg \cdot ha^{-1}$. Prior to planting, ammonium sulfate was banded along with P and K in the 56, 112, and 168 $kg \cdot ha^{-1}$ treatments at 56 $kg \cdot ha^{-1}$ for all treatments. The 168 $kg \cdot ha^{-1}$ treatment received 56 $kg \cdot ha^{-1}$ of ammonium sulfate pre plant broadcast the day before planting. Broadcast fertilizer was shallowly incorporated. The remaining nitrogen 56 $kg \cdot ha^{-1}$ was added approximately 5 weeks later to the 112 and 168 $kg \cdot ha^{-1}$ treatments as ammonium sulfate. Side dressings were applied just prior to vine run in a band about 30 cm wide on both sides of the planted row and shallowly incorporated by hand. There were eight plants in each plot and all treatments were replicated four times. Pumpkins were grown on bare ground with trickle irrigation.

In 2012, the study was altered to evaluate both the timing and method of application of nitrogen fertilizer. ‘Gladiator’ pumpkins were hand planted on June 14th and July 2nd at the same spacing used in 2011. The experiment was replicated in time with two plantings spaced two weeks apart. Phosphorus and potassium were applied in all plots according to soil tests at 37.4 and 39.6 $kg \cdot ha^{-1}$ respectively. The nitrogen treatments included 0 and 112 $kg \cdot ha^{-1}$. There were three 112 $kg \cdot ha^{-1}$ treatments. The grower standard received 56 $kg \cdot ha^{-1}$ nitrogen as ammonium sulfate at planting followed by the same rate five weeks later as vines began to run. There were two fertigation treatments. The first received 56 $kg \cdot ha^{-1}$ N at planting, the same as the grower standard. This was followed by four applications of 14 $kg \cdot ha^{-1}$ N in the form of calcium nitrate at weeks 6, 7, 9, and 11 weeks after planting. The second fertigation treatment was given 14 $kg \cdot ha^{-1}$ nitrogen at planting followed by seven more applications of 14 $kg \cdot ha^{-1}$ N applied as calcium nitrate at weeks 2, 3, 4, 7, 9, and 11 after planting (see Table 2.1 for expanded fertigation schedule). There were 10 plants in each plot and each treatment was replicated 4 times for each planting date. Fertigation was applied through the trickle irrigation using a Mazzei injector system. Trickle irrigation was applied in both years if rainfall events over a five day period did not exceed 25 mm.

In 2011, petiole nitrate readings were taken 43 days after planting on July 28. Fresh petioles were collected from the most recently mature leaf. Petioles were chopped and pressed to express plant sap; fresh sap was analyzed immediately for nitrate-N. A drop of fresh sap was placed over the electrodes of a handheld Cardy meter (Spectrum Technologies, Plainfield, IL) and the results of the ion concentration were read from the digital nitrate meter. Two readings were conducted for each plot to obtain an average reading per treatment rep. In 2012, leaf tissue analysis was conducted to measure total nitrogen. Eight of the most recently matured leaves from each plot were sampled on August 15, 62 days after the first planting and 44 days after the later planting. Leaves were rinsed in distilled water and dried for 48 hours at 65°C. Leaves were then ground, packaged, and submitted to Agro-One Plant Tissue Testing Service, Ithaca, NY for analysis.

In both years, weeds were controlled with recommended herbicides and cultivation and insects and disease pressure monitored and protective treatments applied when warranted (Reiners and Petzoldt, 2011). One time harvests were made in both years, September 27, 2011 and October 10, 2012. Fruit from each plot was counted, weighed, and determined if marketable or unmarketable. Marketable fruit was disease free, orange, firm, and free from major blemishes and rot. In both years, trials were arranged as a randomized complete block design. Data was analyzed using analysis of variance in JMP (JMP 9 and 10, SAS Institute, Inc., Cary, NC), for significant interactions. Analysis of variance was evaluated to determine significance of treatment on total yield weight, number of fruit, and weight of fruit. When necessary means comparison was evaluated using a Tukey's HSD test.

Results and Discussion:

In 2011, nitrogen rates had no affect on average fruit weight or fruit number for total (green and orange fruit) or marketable (orange fruit) yield (Table 2.2). Nitrogen applications did result in significantly greater tonnes.ha^{-1} for total yield and a trend towards greater tonnage of marketable fruit (significant at the 10% level). Additional nitrogen seemed to increase total yield by increasing the number of green unmarketable fruit. These results would seem to indicate that current recommended application rates may result in over application of nitrogen, especially on loamy, intensively cultivated vegetable soils where soil organic matter and residual nitrogen from previous crops are high. The marketable tonnes$\cdot$$ha^{-1}$ are not significantly different for the 0, 56, 112 kg$\cdot$$ha^{-1}$ treatments nor for the 112 and 168 kg$\cdot$$ha^{-1}$ treatments (see Table 2.2). This suggests that any effect of added nitrogen on marketable yield may be found between 56 and 112 kg$\cdot$$ha^{-1}$ added nitrogen. These results demonstrating little effect of added nitrogen when applied to pumpkins are consistent with prior studies by Van Eerd and O'Reilly (2009), Reiners and Riggs (1997), Swaider et al. (1994), and Santos et al. (2006).

Differences in petiole nitrate levels were significant by treatment. Readings were taken twice; means for the four treatments 0, 56, 112, and 168 kg$\cdot$$ha^{-1}$ were 563, 578, 759, and 963 PPM of NO3, respectively (Table 2.3). The petiole nitrate readings indicate that plants took up applied nitrogen. Petiole nitrate reading guidelines are not available for pumpkins, but according to the numbers for watermelon (1000-1200 ppm when fruit is 2 inches in length), all treatments were lower than optimum levels (Maynard and Hochmuth, 1997). Current watermelon production practices in the Southern USA include added high amounts of N and it is understandable why the levels found in these pumpkins were low, when compared to a watermelon standard. It was decided for 2012, total N would be tested in order to have a measurement for which there are recommended values for pumpkins.

In 2012, the effect of adding nitrogen to the system through different fertigation timings was studied. The treatments were 0 kg added N (zero added); 112 $kg{\cdot}ha^{-1}$ added as a split application of dry blend fertilizer (split dry application); a split fertigation of 56 $kg{\cdot}ha^{-1}$ followed by four 14 $kg{\cdot}ha^{-1}$ fertigations (split fertigation), and lastly a fully fertigated treatment of eight 14 $kg{\cdot}ha^{-1}$ fertigations throughout the season (full fertigation). The results of the study show that nitrogen treatments had no affect on marketable yield, average fruit size, and total fruit number for either planting dates (Table 2.4). There were no differences between the 0 $kg{\cdot}ha^{-1}$ and all three of the 112 $kg{\cdot}ha^{-1}$ treatments.

In 2012, leaf tissue analysis was conducted to determine differences in the amount of total nitrogen present in plants for the differing fertigation treatments. Plants were sampled on August 15, 62 days after the first planting and 44 days after the later planting. In the early planting, treatment had a significant effect on total nitrogen found in the leaf dry matter sample. Means across the replications for the treatments were: 4.39% nitrogen for zero added; 4.75% for full fertigation, 4.97% for split fertigation, and 5.38% for split dry application (Table 2.5). The later planting did not show significant results for leaf nitrogen by treatment, but a similar trend occurred (significant at the 10% level). The treatment means were: 5.40% of nitrogen for zero added N; 5.89% for full fertigation; 5.71% for split fertigation; and 5.92% for split dry application. Maynard and Hochmuth (1997) suggest that an adequate percent nitrogen for pumpkin leaves range from 3.0%-

6.0% based on the developmental stage. We find that for our first planting, every treatment including 0 added N fall into the high range (above 4%) and for the later planting all treatments fall into the adequate range (3-6%) of recommended total N in plant tissue. These findings support our conclusions that on loamy, intensively cultivated soils with residual N, added nitrogen can be cut back from the current recommendations.

The results from two years of field data show, that increasing N rates in an intensively cultivated and productive soil may not be needed for a pumpkin crop, at least in the first year of a rotation on a loamy mix soil with a moderate to high soil organic matter content. In 2011 a trend (significant at 10%) was seen that increasing N rate would increase marketable fruit. In 2012, however, no differences were found. Both years were hot and sunny, with significant dry periods, but supplemental irrigation, created ideal conditions for growing pumpkins. Van Eerd and O'Reilly (2009) found similar results in Ontario, Canada when studying processing cucumbers. They concluded that 0-30 $kg \cdot ha^{-1}$ might be a more accurate needs assessment for cucumber production nitrogen additions. Our results showed no benefit of fertigating over a typical grower practice of a split dry blend fertilizer application. In conclusion, it seems a rate of 56 $kg \cdot ha^{-1}$ nitrogen on loamy, intensively cultivated, vegetable soils would optimize pumpkin production. Traditional split applications at planting and prior to when vines run is just as effective as season long fertigations.

Table 2.1. Fertigation timing for two planting dates and four nitrogen fertigation schedules

	First Planting 6/14/2012		**Second Planting 7/02/2012**	
Treatment	**N kg˙ha-1**	**Week of application**	**N kg˙ha-1**	**Week of application**
Zero added	0	-	0	-
Split dry application	56	1, 6	56	1, 6
Split fertigation	56 14	1 6, 7, 9, 11	56 14	1 7, 9, 10, 11
Full fertigation	14	1, 2, 3, 4, 6, 7, 9, 11	14	1, 2, 3, 5, 7, 9, 10, 11

Table 2.2. Total yield and marketable yield for fruit number, yield weight, and average individual fruit weight grown at four nitrogen levels in 2011.

	Total Yield				Marketable Yield		
N kg·ha-1	No. fruit/ha	Yield (t·ha-1)	Avg fruit mass (kg)		No. fruit/ha	Yield (t·ha-1)	Avg fruit mass (kg)
0	7809	60.39 a	7.77		5406	43.73	8.19
56	7569	60.75 a	8.01		5766	46.76	8.12
112	8289	69.24 ab	8.67		6247	56.05	8.94
168	8049	75.96 b	9.13		6367	58.20	9.15
Significance	NS	**	NS		NS	*	NS

Non significant or significant at the 10% (*) or 5%(**) level, respectively.
Means with the same letter within a column are not significantly different.

Table 2.3. 2011 Petiole nitrate readings	
N kg·ha-1	Nitrate-N Petiole sap concentration (ppm)
0	563 a
56	578 a
112	759 ab
168	963 b
Significance	**
**Significant at the 5% level Means with the same letter within a column are not significantly different.	

Table 2.4. Total yield and marketable yield for fruit number, yield weight, and average individual fruit weight under four nitrogen application methods in 2012.

	Total Yield			Marketable Yield		
First planting 6/14/2012	No. fruit/ha	Yield (t·ha-1)	Avg fruit weight (kg)	No. fruit/ha	Yield (t·ha-1)	Avg fruit weight (kg)
Treatment						
Zero added	5286	36.34	6.93	4806	34.15	7.10
Full fertigation	6055	43.04	7.06	4806	37.96	7.73
Split fertigation	6728	46.03	6.89	5959	42.06	7.36
Split dry application	7209	50.60	7.05	6440	44.38	7.33
Significance	NS	NS	NS	NS	NS	NS
Second planting 7/2/2012	No. fruit/ha	Yield (t.ha-1)	Avg fruit weight (kg)	No. fruit/ha	Yield (t.ha-1)	Avg fruit weight (kg)
Treatment						
Zero added	4998	42.14	8.48	4806	41.18	8.68
Full fertigation	4710	41.99	9.02	4614	41.32	9.04
Split fertigation	4902	42.14	8.79	4710	40.97	8.87
Split dry application	5671	45.01	7.97	5383	43.42	8.08
Significance	NS	NS	NS	NS	NS	NS
NS, Non significant						

Table 2.5. 2012 Leaf tissue analysis for percent total nitrogen		
	First Planting 6/14/2012	Second Planting 7/02/2012
Treatment	% Total nitrogen	% Total nitrogen
Zero added	4.39 a	5.40
Split dry application	4.75 a	5.89
Split fertigation	4.97 ab	5.71
Full fertigation	5.38 b	5.92
Significance	**	*

Significant at the 10% (*) or 5%(**), level, respectively.
Means with the same letter within a column are not significantly different.

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CHAPTER 3

Black Plastic Mulch and Transplants Improve Yield, Fruit Number, and Profitability in Pumpkin Production.

Abstract:

Field studies were conducted in 2011 and 2012 at the New York State Agricultural Experiment Station to assess the effects of black plastic mulch, transplanting, planting date, and variety on yields, costs, and profitability in *Cucurbita pepo* production. Marketable yield ($t \cdot ha^{-1}$) was significantly affected by stand establishment method (direct seed, small, medium, and large transplant) in the July planting in 2011 and showed a trend in the June planting. Stand establishment significantly affected the number of fruit/hectare for both plantings and mulch presence had an effect on the July planting. In 2012, varietal differences between 'Gladiator' and 'Magician' had a significant effect on every measured yield indictor: average fruit weight, total marketable weight, and fruit no./hectare over two plantings. Stand establishment (direct seed and small transplant) had a significant effect on fruit no./ha in the early planting. Mulch presence had a significant effect on fruit no./ha for both plantings and on marketable yield in the later planting. Economic analysis was conducted by creating a production budget using data for 'Gladiator' production from 2011 and 2012 in differing cropping systems. Direct seed into plastic mulch, transplant into bare ground, and transplant into plastic mulch were found to increase profits by 41%, 44%, and 34% per hectare, respectively when compared to the standard cropping system of direct seed into bare ground.

Introduction:

Jack-o-lantern pumpkins are worth an average of $30 million annually and are planted on approximately 2,500 hectares (ha) in New York State alone (USDA, 2013). Across the USA, pumpkins have a market value of $145 million and are planted on 32,000 hectares (USDA, 2013; USDA, 2009). An increase in the popularity of Halloween over the past 30 years has driven the market for decorative pumpkins (Hsu, 2012). Many consumers now demand multiple pumpkins per family and many pumpkin-related fall attractions have stimulated additional production and led to an increase in the value of the crop.

As the cost of pumpkin production has increased due to increased hybrid seed costs and greater use of expensive fungicides, growers are interested in increasing revenues through increases in yield per production unit. In New York State, few growers use transplants as their current method of stand establishment. However, as seed costs increase more growers are choosing this method. Direct seeding takes at least twice as many seeds as using transplants due to germination and establishment issues. Plastic mulch is common in production of many other vegetable crops in New York State including tomatoes, peppers, and melons, but it is not widely used in pumpkin plantings. Many of the same benefits that these crops gain from plastic mulch: increased yields, reduced evaporation, and weed control, could be gained from use in pumpkin production. Information on using transplants and black plastic mulch in pumpkin production systems is needed to ensure growers have the knowledge to make educated, research based, decisions for their farm business.

Research shows that transplants consistently accelerate maturation and produce higher yields when compared to direct seeding (Hall, 1989; NeSmith, 1993; Rulevich et al., 2003). The use of transplants provides earlier harvests, better root system development, and the ability to grow warm season crops in cooler climates where direct seeding would not be possible (NeSmith, 1999; Watts, 1929). Transplants also have been used to manipulate planting time, increase crop uniformity, make more efficient use of expensive hybrid seed, and utilization of plastic mulches and trickle irrigation (Liptay et al., 1982; NeSmith, 1994,1997; Norton, 1968; Orzolek, 1991, 1996).

Muskmelon (*Cucumis melo* L.) transplants were compared to field seeded plots that were seeded the same day or 7-10 days earlier. Results showed significantly higher yields and fruit weight in the transplant plots as compared to the direct seeded plots (Norton, 1968). *Cucurbita moshata* was studied to determine the effect of mulch and transplants on early fruit set and total yield. Across very different growing seasons, transplants provided the most consistent method for improving both factors (Rulevich et al. 2003). Transplants can be grown in various size containers; optimum cell size for yield shows differing results. Hall (1989) showed an increase in total watermelon [*Citrullus lanatus* (Thunb.)] weight when increasing cell size from 18.8 cubic centimeters (cc) to 39.5 cc. In a watermelon transplant study conducted at the University of Florida, it was found that transplants grown in differing cell sizes between 18.8cc and 65.5cc had no effect on total yield or mean fruit weight (Vavrina et al., 1993). Six types of irrigations systems and the interaction with stand establishment on muskmelon were studied over four growing seasons. Results differed based on the year. Direct seeded plants produced similar or higher total yields than transplanted counterparts in 2 of 4 years, the years where the field conditions were close to optimal (Leskovar et al., 2001). In years without optimal growing conditions the yields in transplants were more than double that of the direct seeded plots.

Plastic mulch can modify soil temperature, conserve soil moisture by reducing evaporation, increase the air temperature microclimate around the plant, control weeds (Oebker and Hopen, 1974) and decrease fertilizer leaching (Bonanno and Lamont, 1987). Plastic mulch can decrease erosion when positioned properly across a field gradient. In common plant spacings, 50% or more of the soil surface is covered and protected from raindrop velocity, thus reducing soil particle detachment (Mid West Plan Service, 1992). Using plastic mulch has become the common practice for: cucumber (*Cucumis sativus*), muskmelon (*Cucumis melo*), summer squash (*Cucurbita pepo*), and watermelon (*Citrullis lanatus*) along with many non-cucurbit vegetables (Kasirajan and Ngouajio, 2012).

Black plastic mulch and supplemental irrigation were found to have a synergistic effect on fruit yield for acorn squash (*Cucurbita pepo* L var. *pepo*) (Ells et al., 1994). Squash grown on plastic, yielded 35% more on average, than squash grown on bare ground. Yields were similar between plastic mulch treatments that received 50% of water requirements and bare ground treatments that received full water requirements (Ells et al., 1994). Experiments looking at the effects of plastic soil mulching and row covers on zucchini and watermelon found that the plastic mulch without row cover treatments induced the greatest yield benefits, 177% and 208%, respectively (Ibarra Jimenez and Flores Velasquez, 1997). A watermelon study looking at multiple types of soil mulch covers and row covers found that the highest marketable and total yields were found in the clear plastic and black plastic mulch treatments (Ibarra Jimenez et al. 2005). These were also the most economical treatments. Different results were found in a cucumber experiment looking at early and total yield when grown on black plastic mulch or a combination of mulch and row cover. Mulched treatments showed a significant increase in early yield, but the total yields were not significantly different (Ibarra Jimenez et al., 2004). Field studies found significant increase in tons/hectare and kg/ fruit when comparing watermelons grown on mulched plots (65.1 t/ha) to those grown on bare soil treatments (59.1 t/ha) (Brinen et al., 1979). Bonano and Lamont (1987) compared the effect of plastic mulch, with or without the addition of row cover, on muskmelon production. Early and total yields increased when using either black or clear plastic mulches as compared to the bare ground treatment. Benefits of plastic mulch were found in the cooler climate of Maine when growing 'Earliqueen' muskmelon. Average yield of plastic treatments was 20.4 kg/plot as compared to only 9.9 kg/plot when plastic was not used (Handley et al., 1998).

Brown et al. (1996) and Rulevich et al. (2003) examined the combined affects of black plastic with direct seeded and transplanted *Cucurbita pepo* and *Cucurbita moschata,* respectively. Transplants produced 51% more fruit weight than the direct seeded plants, which preformed less well regardless of plastic mulch treatments (Brown et al., 1996). Presence or absence of black plastic mulch did not affect squash yields in this study. Transplanting proved to be the most effective method for increasing squash yield (Brown et al., 1996). Rulevich et al. (2003) found that over multiple seasons transplants proved the best way to increase yields, but each season showed differing results. Other literature examining establishment method and black plastic mulch is needed.

Season extension techniques such as black plastic mulch and transplants offer opportunities for increased yields, but with increased yields come increased input usage. Results indicate that the switch from no-till pumpkin production to plasticulture production will increase cost of production by $422.69 per hectare (Orzolek et al., 2012); this is equivalent to an increase in costs of 4%. Transplanting is not yet a commonly used practice in pumpkin production, but the cost of transplanting can be found for other cucurbits; a 2006 budget estimated the costs of transplants to be $518.70 per hectare for cantaloupe production (Orzolek et al., 2006). Our research aims to determine the effect that stand establishment (transplants versus seed) and black plastic mulch presence have on total yield, fruit weight, and fruit number of jack o' lantern pumpkins. Determining the changes in costs and revenues of these season extension cropping systems is an important objective of this research.

Materials and Methods:

Experiments were conducted in Geneva, NY in 2011 and 2012 on a Lima silt loam (fine-loamy, mixed, mesic, Glossoboric Hapludalf). Plant spacing in both years and in all plots was 1.2 meters in-row by 2.1 meters between rows. In both years plastic mulch was laid for all plots and then removed by hand for bare ground plots. In 2011, a fall planted, rye cover crop was plowed under approximately one week before planting. 'Gladiator', a large semi bush variety (Harris Seeds, Rochester, NY) was hand planted on June 10, and July 12, 2011. For direct seeded plots, three seeds were planted at each hill and thinned to one plant after germination. For transplanted plots, transplants that were 21 days old were planted the same day as direct seeding. Transplants were started in three different size containers, 72, 50, and 38 cell trays, providing respectively, approximately 43, 66, and 106 cc of root ball space. In 2011, treatments consisted of direct seed, and three different size transplants planted on black plastic mulch or bare ground on a normal or late planting date.

Pre-season soil tests were conducted each year and the soils were found to be in the medium to high range for all tested nutrients. In 2011, nitrogen, phosphorus, and potassium were applied under plastic at rates of 56, 24.6, and 46.5 $kg \cdot ha^{-1}$ respectively, according to the soil test. In both years, soil pH was in the 6.3 to 6.7 range in all fields, optimum for pumpkin production so no additional limestone was needed. Plastic was laid on June 9, 2011 and June 5, 2012. Fertigation was used to meet nutrient needs later in the season. In 2011, an additional 11 $kg \cdot ha^{-1}$ N, 9.8 $kg \cdot ha^{-1}$ P, 18.6 $kg \cdot ha^{-1}$ of K was added approximately 5 weeks after planting to all treatments. Fertigation was applied just prior to vine run. There were eight plants in each plot and all treatments were replicated four times.

In 2012, the study was altered to evaluate two varieties, the same variety used in 2011, ‘Gladiator’ and ‘Magician’, a medium sized, semibush vining variety (Harris Seeds, Rochester, NY). Also, based on 2011 results, only the small, 72 cell transplant was used along with direct seeding. Treatments in 2012 were: transplant or direct seed planted in to black plastic mulch or bare ground at a normal or late planting date with ‘Gladiator’ and ‘Magician’ varieties. Pumpkins were hand planted on June 12^{th} and June 29^{th} at the same spacing used in 2011. In 2012, nitrogen, phosphorus, and potassium were banded under plastic at rates of 56, 12.3, and 46.5 $kg \cdot ha^{-1}$ respectively, according to the soil test. Fertigation was used to meet nutrient needs later in the season. In 2012, an additional 22.4 $kg \cdot ha^{-1}$ N, 9.8 $kg \cdot ha^{-1}$ P, 18.6 $kg \cdot ha^{-1}$ of K was added approximately 5 weeks after planting to all treatments. There were 10 plants in each plot and each treatment was replicated 4 times for each planting date. Fertigation was applied through the trickle irrigation using a Mazzei injector system. Trickle irrigation was applied in both years if rainfall events over a five-day period did not exceed 25 mm.

In both years, weeds were controlled with recommended herbicides and cultivation; insects and disease pressure were monitored and protective treatments were applied when warranted (Reiners and Petzoldt, 2011). One time harvests were made in both years, September 20, 2011 and October 04, 2012. Fruit from each plot was counted, weighed, and determined if marketable or unmarketable. Marketable fruit was disease free, orange, firm, and free from major blemishes and rot. In both years, trials were arranged as a randomized complete block design. Data was analyzed using analysis of variance in JMP (JMP 9 and 10, SAS Institute, Inc., Cary, NC), for significant interactions. Analysis of variance was evaluated to determine significance of treatment on total yield weight, number of fruit, and weight of fruit. When necessary means comparison was evaluated using a Tukey's HSD test.

Results and Discussion:

In 2011, a field study was conducted to determine the most effective stand establishment methods for jack-o'-lantern pumpkins planted at a normal (June 10) and late (July 12) planting date for the Northeast. Plastic mulched or unmulched plots were either direct seeded or transplanted with 'Gladiator' pumpkins. None of the treatments had significant effects on average fruit weight or marketable tons per hectare for the June planting date (Table 3.1). Significant differences were observed in fruit number between the direct seeded and transplanted treatments. Stand establishment method affected number of marketable fruit, yields ranged from about 8,000 fruit per hectare in the seeded plots to maximum of 10,151 fruit per hectare using medium size transplants. Although not significant at the 5% level due to field variability, a trend was observed (significant at the 10% level) that black plastic mulch increased fruit numbers by just under 900 fruit per hectare. Other trends (again significant at the 10% level) were found in the June planting data. Stand establishment technique showed a trend towards increasing marketable tons per hectare with 57.5 tons per hectare for direct seeding and more than 65.2 tons per hectare in all the transplants treatments. Finally, there was a trend towards larger fruit (significant at the 10% level) for plants grown on bare ground compared to plastic mulch.

The later planting showed increased effect from the treatments although no significant differences were observed relative to average fruit weight (Table 3.1). Marketable tons per hectare were significantly affected by stand establishment technique. The large and medium transplants produced almost 1000 more fruit per hectare compared to the direct seeded plants. Mulched plots significantly increased fruit number compared to unmulched plots and there was a trend toward greater tons per hectare. There was one significant interaction in the late planting. Fruit number was significantly increased when transplants in plastic mulch were used compared to direct seeding (Figure 3.1). There were no differences, however, when transplants were used in either bare ground or mulch. This would seem to indicate that a grower could improve yield by transplanting into bare ground or direct seeding into mulch. There was no benefit beyond those treatments when using transplants in mulch.

In 2012, the experiment incorporated a second variety, 'Magician' and used only the smallest and most economically feasible transplant. Since significant differences between transplant sizes were not observed for tons per hectare yield in 2011, the medium and large transplants were not used. In 2012, 'Gladiator' and 'Magician' pumpkins were planted on June 12 (normal) and June 29 (late) using either a three week old transplant or direct seeded into bare ground or black plastic mulch. 'Magician' is considered to be a medium size pumpkin variety (4.5-7.3 kg) where as 'Gladiator' is a large fruited variety (9.0-11.3 kg). Variety had a significant effect on every tested factor in both planting dates. 'Magician' produced more fruit of a smaller size, as expected, and also resulted in more tons per hectare (Table 3.2). Stand establishment was significant at the 0.1% level with over 550 more fruit per hectare for direct seeded plots compared to transplanted plots. Mulch resulted in 5046 fruit per hectare in bare ground plots compared to 5286 fruits/ha in plastic mulched plots. No interactions between stand establishment and mulch were significant.

In the late planting, we did not observe the increased fruit number per hectare when direct seeding was used as in the first planting. In fact, a trend was observed at the

10% level that showed an increase in fruit number when using transplants, which helps to confirm the results from the previous year. Although trends were observed in previous studies, the mulch significantly increased tons per hectare in the late planting. Three significant interactions were found: they can be observed in Figures 3.2-3.4, interaction between stand and mulch, variety and mulch, and a three way interaction between variety, mulch, and stand, respectively. Fruit number increased significantly when transplants were used in mulch, but no differences were observed when used in bare ground (Figure 3.2). 'Gladiator' was not significantly affected by the use of mulch but 'Magician' produced almost 2,000 more fruit per hectare (Figure 3.3). The significant three way interaction further highlights this variety trend (Figure 3.4). There were no significant effects for 'Gladiator' whether using seeds or transplants in bare ground, although we do see a consistent increase when using mulch. Direct seeding 'Magician' in mulch increased fruit number, but by far the biggest increase was seen when using transplants into mulch, which resulted in almost 4,000 more fruit per hectare. This impact on 'Magician' can also be seen with significantly more tons per hectare with mulch versus bare ground (Figure 3.5).

In both years of the study, when yield differences were found it was always due to increased number of fruit in the field, rather than a change in average fruit weight (not including varietal differences). In 2012, problems with field establishment especially in the first planting included bird and cutworm damage. Many plants were replaced and replanted in the first two weeks causing a slow start to the season. In comparison, few plants were lost in 2011. Despite fungicide sprays, the early planting seemed more susceptible to disease and resulted in reduced yield across all treatments. In 2012, ‘Gladiator’, averaged about 30 tons per hectare in the late planting and only 23 tons in the early planting. In contrast the early yield in 2011 was 65 tons versus 40 in the later planting. Despite the yield differences between years and planting dates, yields were better than average for New York, with expected average yields of about 34 tons per hectare (personal communication, Reiners). Planting late may be a viable option in years when growers struggle to get into fields and cannot plant at an earlier, more traditional time. Our results indicate that planting as much as one month after the traditional planting date can lead to average yields or better. Later plantings would more likely benefit from either mulch or transplants as compared to direct seeding in bare soil.

Using black plastic mulch and transplants show the possibility of increasing total marketable yields and fruit numbers per hectare, similar to results on plastic mulch found by Bonano and Lamont (1987) and with transplants and plastic mulch by Brown et al. (1996) and Rulevich et al. (2003). With these increasingly intensive agriculture systems come added input costs. Further budgeting analysis was conducted to determine if the marketable yield increases seen in the different treatments have a positive or negative effect on the overall profitability of growing pumpkins. An assessment of the costs and profits was done for four production systems: direct seed into bare ground, direct seed into plastic mulch, transplant into bare ground, or transplant into plastic mulch (Table 3.3). The estimates used the marketable yields found in this research study over four plantings and harvests in 2011 and 2012. Since ‘Gladiator’ was used in both years, we chose this variety for our budget analysis.

The chance to increase farm profitability using the pumpkin yield data from these field studies is very promising, by using any of the tested cropping systems compared to the grower standard. Transplants into bare ground has the highest percent change from the grower standard (status quo) with a 44% increase in profits per hectare using average yields, prices, and researched input costs. Both the plastic mulch cropping systems are profitable, at 41% and 34% for increased revenue for a direct seed or transplant, respectively. Average yields were very similar for all three treatments that differ from the grower standard, but the estimated variable costs associated with the different techniques changed greatly across the systems. Many budgets were created accessing the sensitive aspects of the revenue stream by changing expected yields and prices. The last row of the Table 3.3 provides a summary of these results and shows a range in which one could expect the profitability to change within a reasonable range of and yields. Not shown in the table (but provided in Appendix A) are the numbers from a worst case scenario budget when yields are reduced 50% and the price received is 66% of the status quo. The only cropping system that would not lose money in this scenario is the transplant into bare ground; using a transplant into plastic or a direct seed into plastic could save the business 18% and 76% of losses, respectively. The cropping systems studied in this experiment show the ability to increase on farm profits by at least 34%.

In conclusion, the transplant into bare ground treatment was able to maximize farm profits based on the budgetary analysis, but all three cropping systems showed large profit increases. Individual farms can determine which system would work best based on their individual machinery, current availability and needs, and any other farm-specific changes in input use and input costs. 'Gladiator' and 'Magician' responded differently to the tested techniques, with 'Magician' having the highest yield response to transplanting into plastic mulch, whereas 'Gladiator' responded equally well to transplant into bare ground and direct seed into plastic mulch, but seemingly with no synergistic effect when combining transplants into plastic mulch. In both years, the later plantings responded with greater yields when planted into plastic mulch. Both later plantings produced average or above average yields for New York State, and planting pumpkins late should be considered a viable option for diversifying cropping systems or when needed, especially in combination with black plastic mulch. Both transplanting and using black plastic mulch increased yields and fruit number in jack-o-lantern pumpkin in one or both years with transplanting increasing fruit number in four out of four plantings. The results of this study differ from those found prior; when transplants and plastic mulch were tested together transplants provided the most consistent increase in yield (Brown et al., 1996, Rulevich et al., 2003). The budgetary analysis shows that a transplant into bare ground is the most profitable cropping system tested, which would agree with the prior findings.

Table 3.1. Marketable fruit number, weight, and average individual fruit weight for ‘Gladiator’ pumpkins grown with or without plastic mulch and stand establishment by seed or transplant in 2011.

	June Planting				July Planting		
Treatment	No. fruit/ha	Yield (t·ha-1)	Avg. fruit weight (kg)		No. fruit/ha	Yield (t·ha-1)	Avg. fruit weight (kg)
Mulch							
Bare ground	8740	64.29	7.35		3574	38.47	10.71
Black plastic	9611	66.67	6.96		4115	42.11	10.23
Significance	NS	NS	NS		**	NS	NS
Stand							
Seed	7989 a	57.54	7.31		3304 a	32.44 a	9.85
Large TP	9611 b	67.13	6.99		4265 bc	44.15 b	10.38
Medium TP	10151 b	72.05	7.09		4385 c	45.95 b	10.53
Small TP	8950 ab	65.21	7.24		3424 ab	38.61 ab	11.11
Significance	*	NS	NS		***	***	NS
M x S							
Significance	NS	NS	NS		*	NS	NS

NS,*,**,*** Non significant or significant at the 5% (*), 1%(**), or .1%(***) levels, respectively. Means with the same letter within a column are not significantly different.

Figure 3.1. Interaction between stand establishment and mulch on fruit number/hectare for the July planting, 2011.

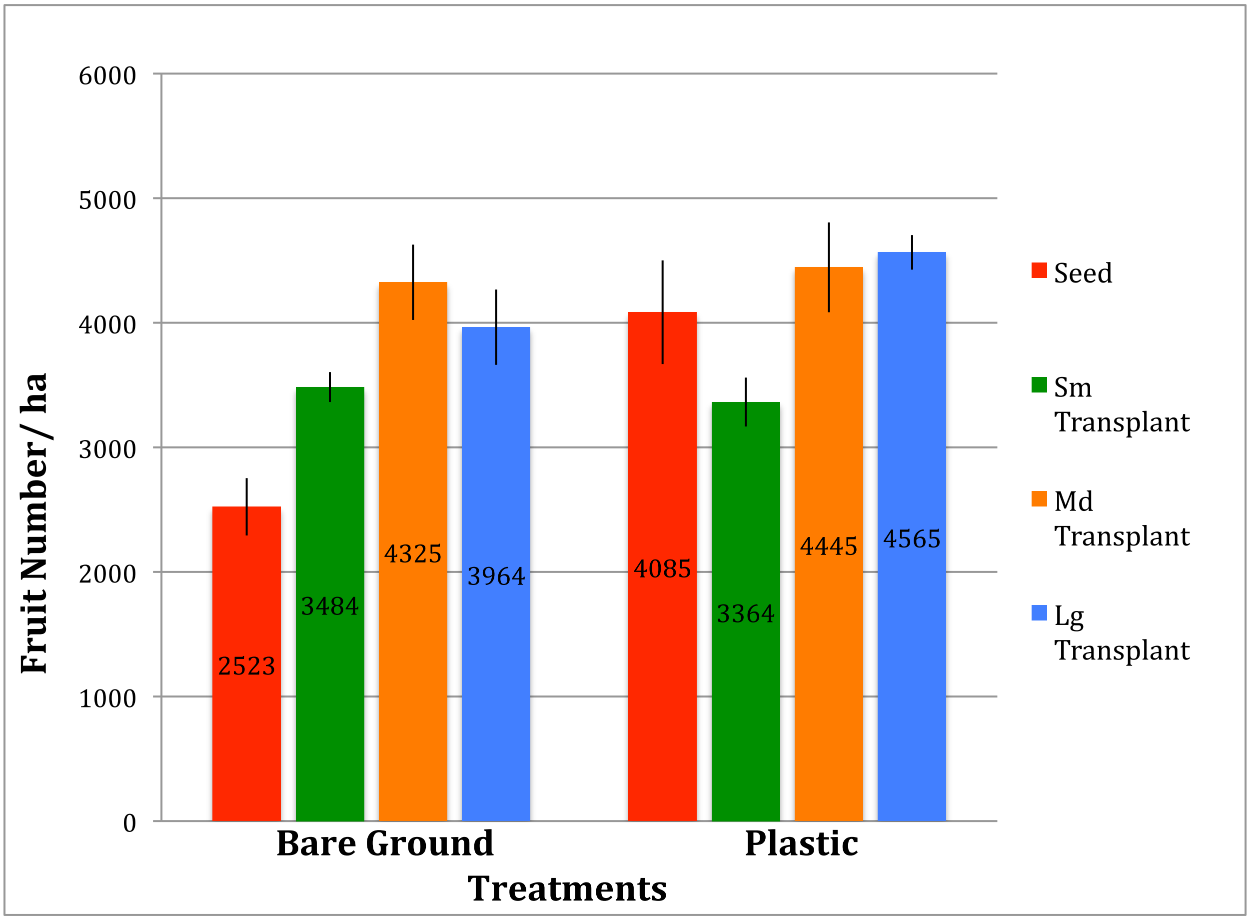

Table 3.2. Marketable fruit number, weight, and average individual fruit weight for ‘Gladiator’ and ‘Magician’ pumpkins grown with or without plastic mulch and stand establishment by seed or transplant in 2012.

	Early Planting				Late Planting		
Treatment	No. fruit/ha	Yield (t·ha -1)	Avg fruit weight (kg)		No. fruit/ha	Yield (t·ha -1)	Avg fruit weight (kg)
Variety							
‘Gladiator’	4373	22.85	5.11		4060	29.42	7.24
‘Magician’	5959	26.15	4.33		5838	33.4	5.75
Significance	***	*	***		***	**	***
Stand							
Seed	5454	25.42	4.66		4781	30.11	6.48
Transplant	4877	23.58	4.78		5118	32.46	6.51
Significance	***	NS	NS		NS	NS	NS
Mulch							
Bare ground	5046	23.22	4.79		4397	28.36	6.54
Black plastic	5286	25.77	4.65		5502	34.46	6.45
Significance	*	NS	NS		***	***	NS
Interactions							
VxS	NS	NS	NS		NS	NS	*
SxM	NS	NS	NS		*	NS	NS
VxM	NS	NS	NS		***	*	NS
VxMxS	NS	NS	NS		**	NS	NS

NS,*,**,*** Non significant or significant at the 5% (*), 1%(**), or .1%(***) levels, respectively.

Figure 3.2. Interaction between stand establishment and mulch on fruit numbers for the late planting, 2012.

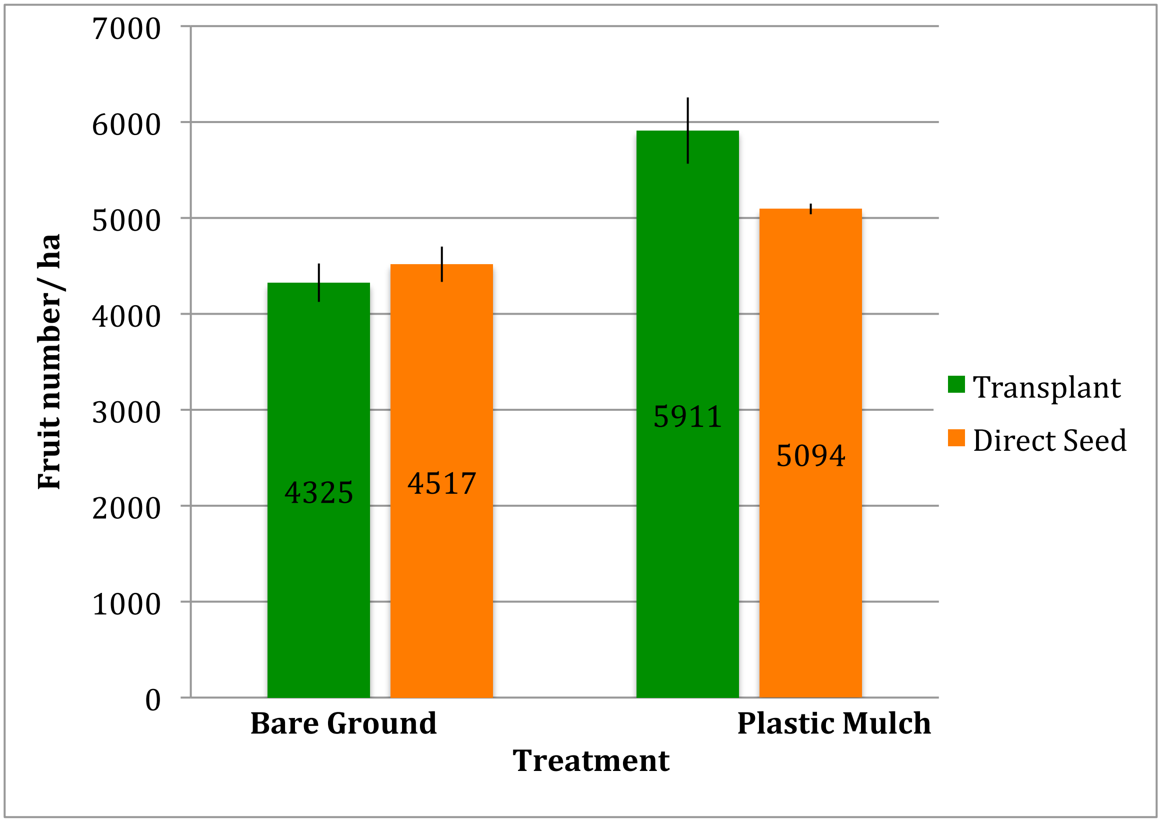

Figure 3.3. Interaction between variety and mulch on fruit numbers for the late planting, 2012.

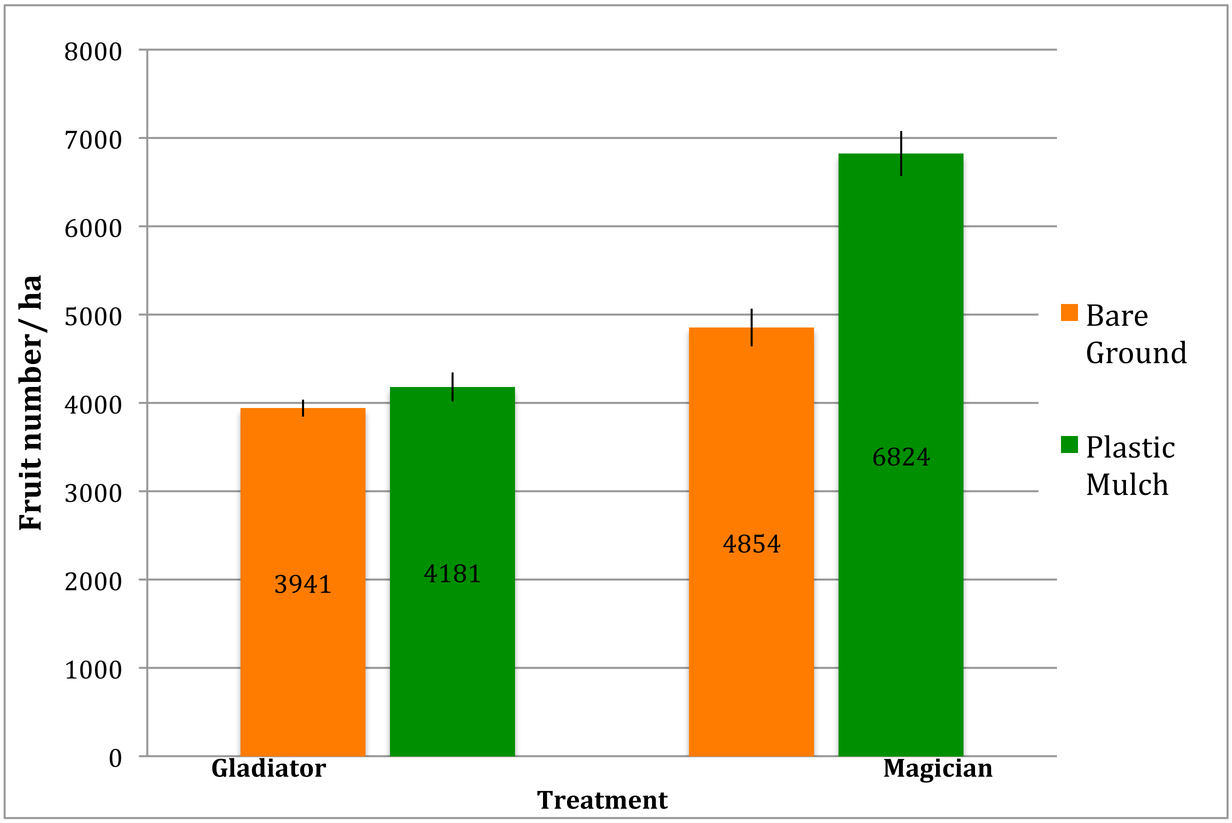

Figure 3.4. Three way interaction between variety, stand establishment, and mulch on fruit numbers for the late planting, 2012.

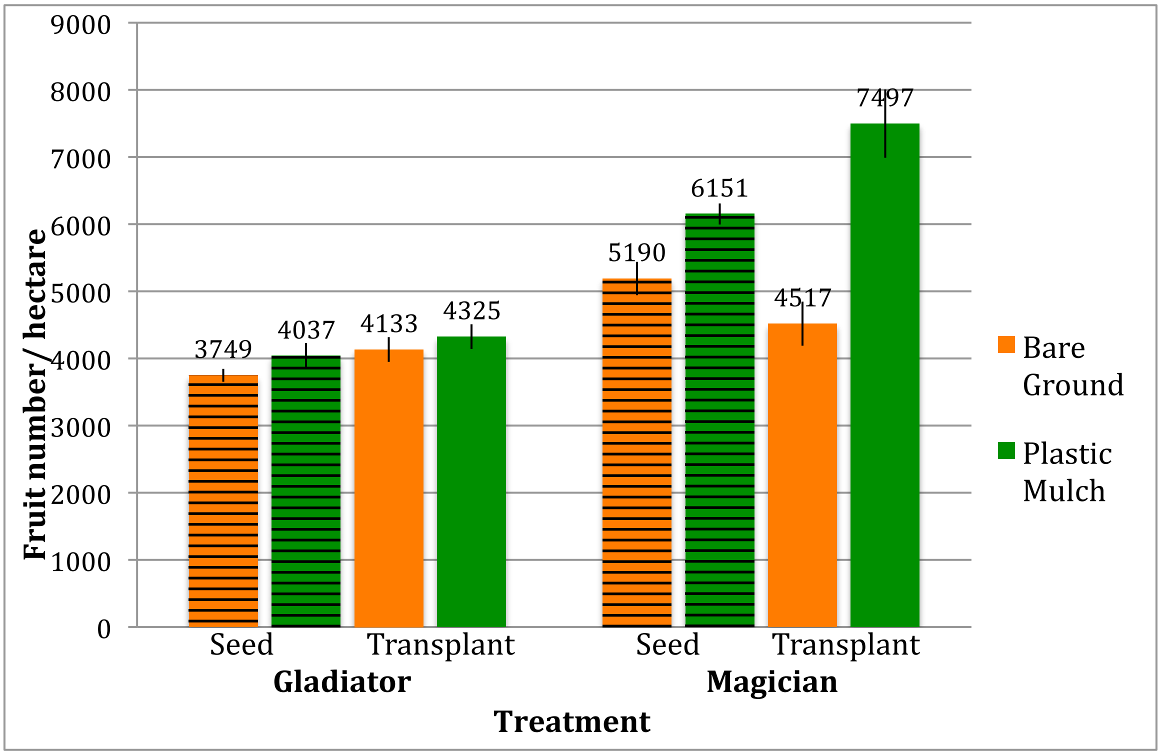

Figure 3.5. Interaction between variety and mulch on t·ha^{-1} marketable yield for the late planting, 2012.

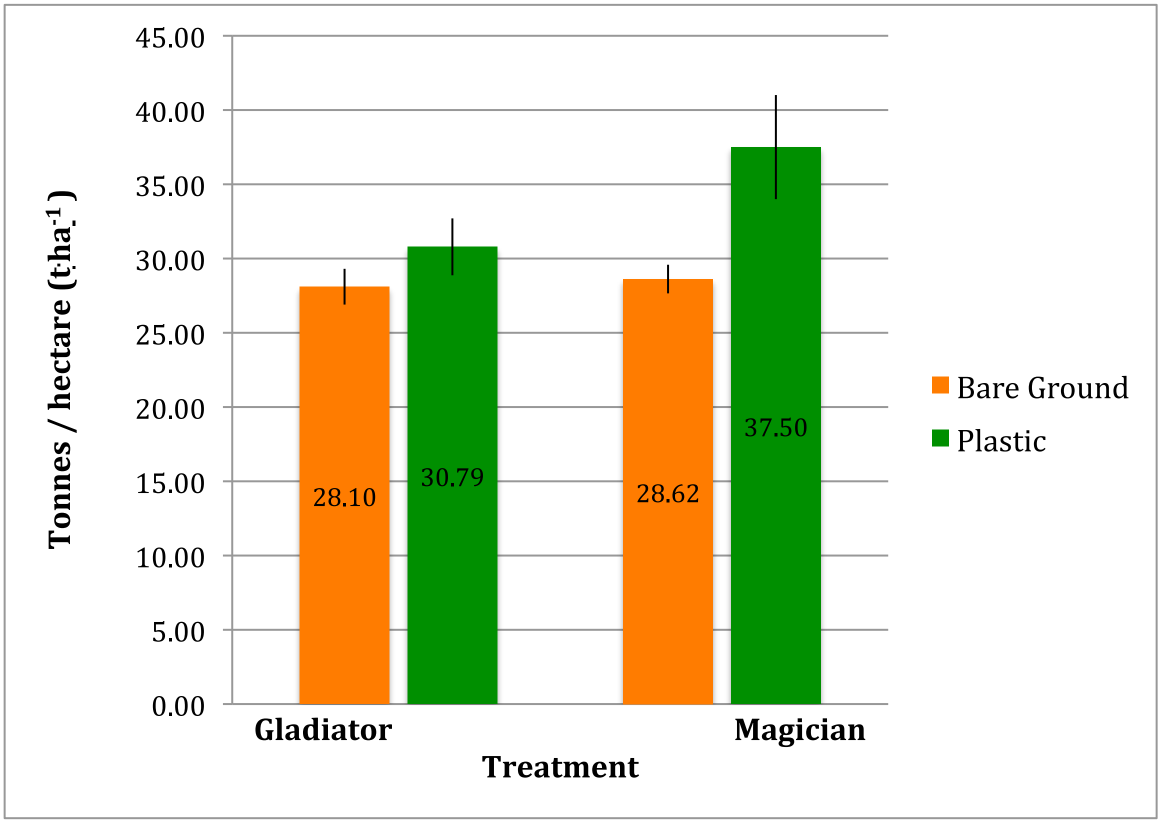

Figure 3.6. Interaction between variety and stand establishment on average fruit weight for late planting, 2012.

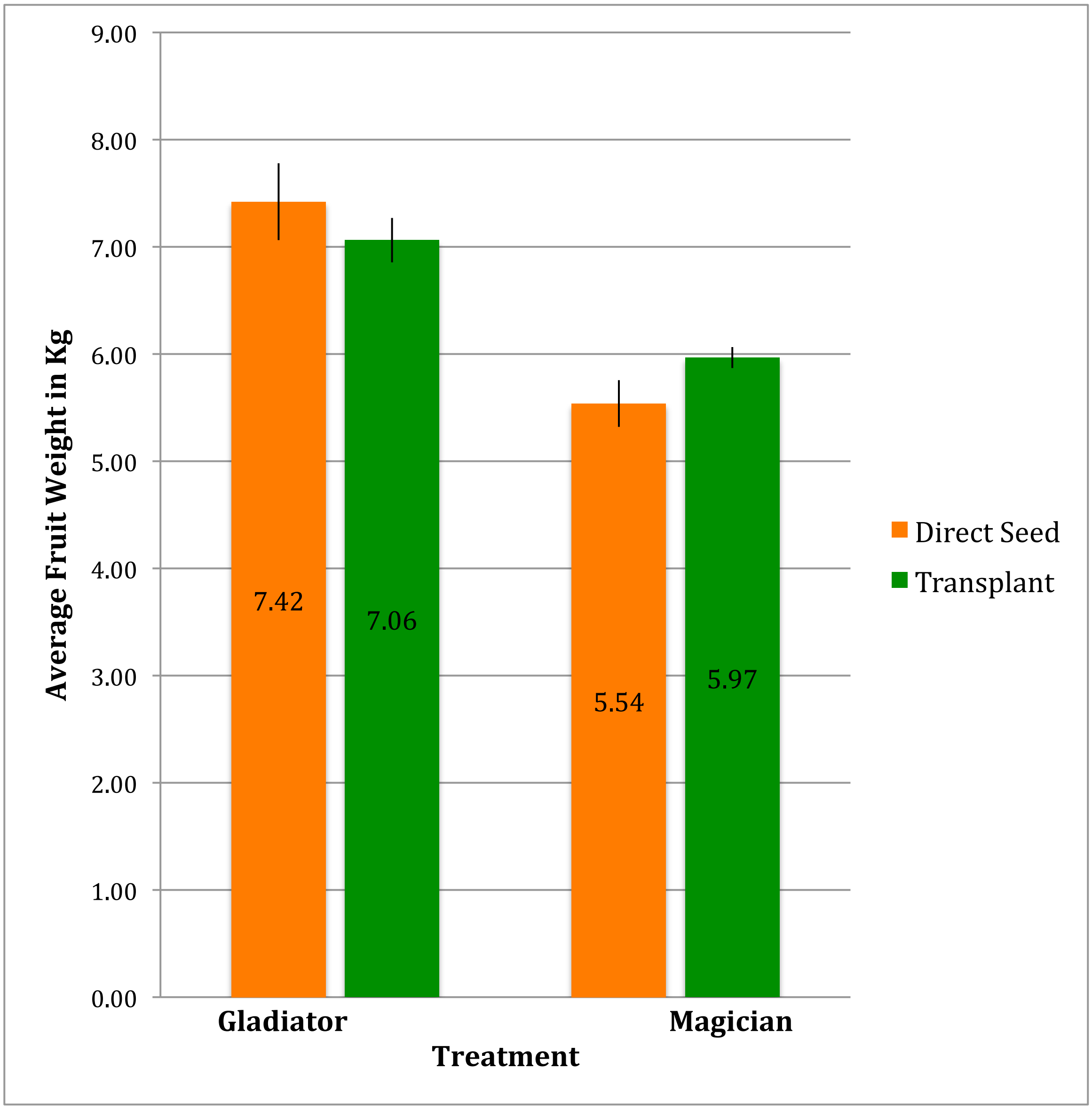

Table 3.3. Budget based on 2011 and 2012 'Gladiator' data comparing the revenues, costs, and profits of four cropping systems: direct seed-bare ground, direct seed-plastic mulch, transplant-bare ground, and transplant-plastic mulch.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (t/ha)		31.0	40.8	40.6	40.3
Price ($/t)		661.40	661.40	661.40	661.40
Total Revenue		**20,512.92**	**26,964.58**	**26,870.43**	**26,679.18**
Variable Costs					
Soil Test	24.71/ha	24.71	24.71	24.71	24.71
Pest Scouting	86.49/ha	86.49	86.49	86.49	86.49
Fertilizer	350.88/ha	350.88	350.88	350.88	350.88
Field Prep	133.19/ha	133.19	133.19	133.19	133.19
Herbicides	266.87/ha bare ground	266.87	133.43	266.87	133.43
Fungicide	850.02/ha	850.02	850.02	850.02	850.02
Insecticide	202.62/ha	202.62	202.62	202.62	202.62
Field prep labor	12.00/hr	59.30	355.82	59.30	355.82
Planting labor	12.00/hr	59.30	266.87	355.82	355.82
Applicator labor	12.00/hr	296.52	355.82	296.52	355.82
Harvest Labor	10.00/hr	1599.38	1778.58	1775.97	1770.66
Diesel Fuel	374.76 l/ha bare ground	444.78	533.74	444.78	533.74
Repairs and maintenance	239.69/ha	239.69	271.81	239.69	271.81
Trickle tape and fixtures	$ .115/meter	538.18	538.18	538.18	538.18
Trickle misc. labor	12.00/hr	118.61	118.61	118.61	118.61
Plastic Mulch	$110/ 1219.2 m	0.00	465.14	0.00	465.14
Transplants	.25/transplant	0.00	0.00	1057.38	1057.38
Seeds	89.10/1000	685.18	685.18	0.00	0.00
Marketing	10 % of sales	2051.29	2696.46	2687.04	2667.92
Fixed Costs					
Tractors	214.98/ha	214.98	214.98	214.98	214.98
Implements	407.72/ha bare ground	407.72	434.90	407.72	434.90
Land charge	494.20/ ha	494.20	494.20	494.20	494.20
Subtotal cost		**9,123.90**	**10,991.64**	**10,604.96**	**11,416.32**
Interest on operating capital	4.59%	418.79	504.52	486.77	524.01
Total cost		**9,542.69**	**11,496.15**	**11,091.73**	**11,940.33**
Revenue-Cost= Profit	**per hectare**	**10,970.23**	**15,468.43**	**15,778.70**	**14,738.85**
% Change from status quo revenue		x	41.00	43.83	34.35
Variations on % change from status quo revenue based on different scenarios			37.95-56.22	39.73-64.28	32.98-41.19

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APPENDIX A: COLLECTION OF 'GLADIATOR' CROPPING SYSTEM BUDGETS

Sensitivity Analysis Discussion:

Budgets were created using yield data from two years of 'Gladiator' pumpkin cropping system experiments. Prices for pumpkins come from New York State data for the past 5 years; $.30/ lb was the average price for the 2012 season. The input numbers from the budgets came from a multitude of sources. Both Wisconsin and Penn State pumpkin budgets were consulted to ensure accuracy of costs. Personal communication with Dr. Bradley Rickard, Dr. Stephen Reiners, and Charles Bornt (a vegetable extension specialist and pumpkin grower) was utilized to determine many input costs and ways to quantify them. Personal experience and records kept from the research project played a role in determining the labor hours needed. All fixed costs were taken directly from the recently updated PSU budget (Orzolek et al., 2012). Input costs for seed, trickle supplies, and plastic mulch were found using a multitude of trade companies and comparing prices.

Data was presented comparing three cropping systems: direct seed into plastic, transplant into bare ground, or transplant into plastic to a grower standard of direct seed into bare ground. This is a way to easily present data so that growers can look at the benefits of these new systems compared to the control of current practice. On Figure 4.1 there is an additional line at the bottom providing a summary of the differences that can be found in the next eight figures of sensitivity analysis on the changing revenues. Figure 4.7 shows a scenario where low price and low yield would generate negative profit scenarios in three of the four cropping systems, but transplant into bare ground manages to stay profitable. Not shown in these analyses, is a true worst case scenario, where there could be a 100% yield loss. In that situation, or something similar, the three tested cropping systems would lose the farm more money, because they have higher total costs, but no revenue would be being made to compensate those extra costs, as it does at normal yields. ‘Magician’ data only existed from 2012, which is why the ‘Gladiator’ yield data was chosen as the basis of this project. Furthermore, ‘Gladiator’ is considered an industry standard and will be a useful measurement for most growers.

Figure 4.1. Budget based on 2011 and 2012 'Gladiator' data comparing the revenues, costs, and profits of four cropping systems: direct seed-bare ground, direct seed-plastic mulch, transplant-bare ground, and transplant-plastic mulch.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		27,671	36,374	36,247	35,989
Price ($/lb)	$.30/ lb	0.30	0.30	0.30	0.30
Total Revenue		8301.3	10912.2	10874.1	10796.7
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	647.26	719.78	718.73	716.58
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	830.13	1091.22	1087.41	1079.67
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3692.37	4448.22	4291.74	4620.09
Interest on operating capital	4.59%	169.48	204.17	196.99	212.06
Total cost		3861.85	4652.40	4488.73	4832.15
Revenue - Cost = **Profit**	/acre	4439.45	6259.80	6385.37	5964.55
% Change from status quo		x	41.00	43.83	34.35
Variations of % change from status quo based on different scenarios			37.95-56.22	39.73-64.28	32.98-41.19

Sensitivity Analysis:
The following budgets are all the same as Figure 4.1, but with one or more streams of revenue altered to examine the effects of market differences on profitability.

Figure 4.2. Sensitivity analysis: Price at 83%, Yield 100%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		27,671	36,374	36,247	35,989
Price ($/lb)	$.25/ lb	0.25	0.25	0.25	0.25
Total Revenue		**6917.75**	**9093.50**	**9061.75**	**8997.25**
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	647.26	719.78	718.73	716.58
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	691.775	909.35	906.175	899.725
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3554.01	4266.35	4110.50	4440.14
Interest on operating capital	4.59%	163.13	195.83	188.67	203.80
Total cost		**3717.14**	**4462.18**	**4299.17**	**4643.94**
Revenue - Cost = **Profit**	/acre	**3200.61**	**4631.32**	**4762.58**	**4353.31**
% Change from status quo		x	44.70	48.80	36.01

Figure 4.3. Sensitivity analysis: Price at 67%, Yield 100%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		27,671	36,374	36,247	35,989
Price ($/lb)	$.20/ lb	0.20	0.20	0.20	0.20
Total Revenue		**5534.2**	**7274.8**	**7249.4**	**7197.8**
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	647.26	719.78	718.73	716.58
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	553.42	727.48	724.94	719.78
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3415.66	4084.48	3929.27	4260.20
Interest on operating capital	4.59%	156.78	187.48	180.35	195.54
Total cost		**3572.44**	**4271.96**	**4109.62**	**4455.74**
Revenue - Cost = **Profit**	/acre	**1961.76**	**3002.84**	**3139.78**	**2742.06**
% Change from status quo		x	53.07	60.05	39.78

Figure 4.4. Sensitivity analysis: Price at 117%, Yield 100%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		27,671	36,374	36,247	35,989
Price ($/lb)	$.35/ lb	0.35	0.35	0.35	0.35
Total Revenue		**9684.85**	**12730.9**	**12686.45**	**12596.15**
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	647.26	719.78	718.73	716.58
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	968.485	1273.09	1268.645	1259.615
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3830.72	4630.09	4472.97	4800.03
Interest on operating capital	4.59%	175.83	212.52	205.31	220.32
Total cost		**4006.55**	**4842.62**	**4678.28**	**5020.35**
Revenue - Cost = **Profit**	/acre	**5678.30**	**7888.28**	**8008.17**	**7575.80**
% Change from status quo		x	38.92	41.03	33.42

Figure 4.5. Sensitivity analysis: Price at 100%, Yield at 90%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		24,904	32,737	32,622	32,390
Price ($/lb)	$.30/ lb	0.30	0.30	0.30	0.30
Total Revenue		8301.3	10912.2	10874.1	10796.7
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	624.20	689.47	688.52	686.58
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	830.13	1091.22	1087.41	1079.67
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3586.30	4308.79	4152.79	4482.13
Interest on operating capital	4.59%	164.61	197.77	190.61	205.73
Total cost		**3750.91**	**4506.56**	**4343.40**	**4687.86**
Revenue - Cost = **Profit**	/acre	**3720.26**	**5314.42**	**5443.29**	**5029.17**
% Change from status quo		x	42.85	46.31	35.18

Figure 4.6. Sensitivity analysis: Price at 100%, Yield at 75%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		20,753	27,281	27,185	26,992
Price ($/lb)	$.30/ lb	0.30	0.30	0.30	0.30
Total Revenue		**6225.975**	**8184.15**	**8155.575**	**8097.525**
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	589.61	644.00	643.21	641.60
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	622.5975	818.42	815.5575	809.7525
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3427.19	4099.64	3944.37	4275.19
Interest on operating capital	4.59%	157.31	188.17	181.05	196.23
Total cost		**3584.50**	**4287.81**	**4125.41**	**4471.42**
Revenue - Cost = **Profit**	/acre	**2641.48**	**3896.34**	**4030.16**	**3626.10**
% Change from status quo		x	47.51	52.57	37.28

Figure 4.7. Sensitivity analysis: Price at 67%, Yield at 50%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		13,836	18,187	18,124	17,995
Price ($/lb)	$.20/ lb	0.20	0.20	0.20	0.20
Total Revenue		**2767.1**	**3637.4**	**3624.7**	**3598.9**
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	531.96	568.23	567.70	566.62
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	553.42	727.48	724.94	719.78
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3023.65	3569.19	3415.77	3750.35
Interest on operating capital	4.59%	138.79	163.83	156.78	172.14
Total cost		**3162.44**	**3733.01**	**3572.55**	**3922.49**
Revenue - Cost = **Profit**	/acre	**-395.34**	**-95.61**	**52.15**	**-323.59**
% Of Status Quo losses saved		x	75.82	113.19	18.15

Figure 4.8. Sensitivity analysis: Price at 83%, Yield at 75%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		20,753	27,281	27,185	26,992
Price ($/lb)	$.25/ lb	0.25	0.25	0.25	0.25
Total Revenue		5188.31	6820.13	6796.31	6747.94
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	589.61	644.00	643.21	641.60
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	518.83	682.01	679.63	674.79
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3323.42	3963.24	3808.44	4140.23
Interest on operating capital	4.59%	152.55	181.91	174.81	190.04
Total cost		**3475.97**	**4145.15**	**3983.25**	**4330.27**
Revenue - Cost = **Profit**	/acre	**1712.35**	**2674.98**	**2813.06**	**2417.67**
% Change from status quo		x	56.22	64.28	41.19

Figure 4.9. Sensitivity analysis: Price at 117%, Yield at 110%.

	Cost/unit	Direct Seed-Bare Ground	Direct Seed-Plastic Mulch	Transplant-Bare Ground	Transplant-Plastic Mulch
Yield (lbs/acre)		30,438	40,011	39,872	39,588
Price ($/lb)	$.35/ lb	0.35	0.35	0.35	0.35
Total Revenue		10653.34	14003.99	13955.10	13855.77
Variable Costs					
Soil Test		10.00	10.00	10.00	10.00
Pest Scouting		35.00	35.00	35.00	35.00
Fertilizer	142.00/acre	142.00	142.00	142.00	142.00
Field Prep	53.90/acre	53.90	53.90	53.90	53.90
Lime		0	0	0	0
Herbicides	108.00/acre	108.00	54.00	108.00	54.00
Fungicide	344.00/acre	344.00	344.00	344.00	344.00
Insecticide	82.00/acre	82.00	82.00	82.00	82.00
Field prep labor	12.00/hr	24.00	144.00	24.00	144.00
Planting labor	12.00/hr	24.00	108.00	144.00	144.00
Applicator labor	12.00/hr	120.00	144.00	120.00	144.00
Harvest Labor	10.00/hr	670.32	750.10	748.93	746.57
Diesel Fuel	40 gallons/acre	180.00	216.00	180.00	216.00
Repairs and maintenance	97.00/acre	97.00	110.00	97.00	110.00
Trickle tape and fixtures	$ .035/ linear foot	217.80	217.80	217.80	217.80
Trickle misc. labor	12.00/hr	48.00	48.00	48.00	48.00
Plastic Mulch	$110/ 4000 feet	0	188.24	0	188.24
Transplants	.25 / transplant	0	0	427.90	427.90
Seeds	89.10/1000	277.28	277.28	0	0
Marketing	10 % of sales	1065.33	1400.40	1395.5095	1385.5765
Fixed Costs					
Tractors	1/acre	87.00	87.00	87.00	87.00
Implements	1/acre	165.00	176.00	165.00	176.00
Land charge	1/acre	200.00	200.00	200.00	200.00
Subtotal cost		3950.63	4787.71	4630.04	4955.98
Interest on operating capital	4.59%	181.33	219.76	212.52	227.48
Total cost		**4131.96**	**5007.47**	**4842.56**	**5183.46**
Revenue - Cost = **Profit**	/acre	**6521.37**	**8996.52**	**9112.54**	**8672.30**
% Change from status quo		x	37.95	39.73	32.98