EVALUATING DIFFERENT SWITCHGRASS CULTIVARS AND COMPOST TREATMENTS FOR BIOFUEL PRODUCTION OF SWITCHGRASS (PANICUM VIRGATUM L.).

by

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A thesis submitted to the

Graduate School- New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

Graduate Program in Plant Biology

written under the direction of

Stacy Bonos

and approved by

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New Brunswick, New Jersey

October, 2013

Abstract of the Thesis

Evaluating different switchgrass cultivars and compost treatments for biofuel production of switchgrass (*Panicum virgatum L.*).

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Switchgrass (*Panicum virgatum L.*) is a native perennial grass crop currently being evaluated as a bioenergy crop for farmers. There are many obstacles to successful switchgrass crop production. Selecting the cultivar most adapted for a particular region can be crucial in maximizing crop production. The uniformity of germination can also affect crop establishment and dry matter yields. Finally, the application of a locally available, low-cost and efficient nutrient source has a major impact on the economic feasibility of this crop as a bioenergy source on farms.

Trials conducted in Middlesex County, New Jersey evaluated the performance of five different switchgrass cultivars and four different locally available compost treatments. A growth chamber study evaluated the germination of different aged seed from two cultivars of switchgrass at temperature settings set to simulate seeding dates in May, June and July in Middlesex County, New Jersey.

Plots were evaluated for seedling emergence, stand survival, stand quality, heading and anthesis dates, plant height, lodging, dry matter yield and dry matter content in the first two years after establishment. Growth chamber trials compared germination rate and percent germination between cultivars and compost amendments.

In the trial comparing different switchgrass cultivars ‘Carthage’, ‘Kanlow’ and ‘High Tide’ had significantly greater yields the second harvest year compared to the first harvest year. Since no additional fertilizer was applied after the initial planting year this indicated an increase in stand quality over time. In the trial comparing different compost amendments and application methods; the horse manure & sawdust, horse manure & food waste and acai berry compost had greater seedling emergence than the synthetic fertilizer control. In this trial, as well, there was a significant increase in stand quality from the first year to the second.

The growth chamber trial results indicated that temperature does not have a significant effect on overall germination; however higher temperatures; representing later planting dates, have a quicker germination rate. Results also indicated that the quality of the seed lot is more indicative of germination than the actual age of the seed.

Acknowledgements

I had the pleasure of working with Dr. Stacy Bonos who was my major advisor for my Master of Science degree. I am thankful for all of the time she spent helping me to plan and develop my research experiments. Her patience and guidance has been much appreciated as I learned the skills required for professional research.

I would also like to thank the other members serving on my graduate committee Dr. Bruce Clarke, Dr. Zane Helsel and Professor William Hlubik, their continual support and guidance was priceless and truly enriched my graduate experience at Rutgers. I will always appreciate the knowledge the bestowed upon me and the time they spent with me.

Additional thanks go out to Chris Miller of Cape May Plant Materials Center who graciously provided me with switchgrass seed and cold storage space whenever I needed it. Everyone on staff at the Rutgers greenhouses who provided both greenhouse space and technical support throughout my research efforts.

Many thanks go out to all of the undergraduate students who helped me with my research efforts and spent much of their summers in switchgrass fields. Particularly Rebecca Reeve who was not only a great worker but became a wonderful friend.

Thanks to my cousins Teresa Gounley and Nicholas Sawyer, whom without their help, I may still be sorting switchgrass seeds for my research trials. My final thanks go to my parents' Christine and Glenn Baculis for all of the emotional support they provided me. I am extremely grateful to my sister Beth, who came out to help harvest both years. Lastly, thank you to my husband Joshua Buitrago, who has been indispensable in every possible facet of both my research and my life.

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Chapter 1: A Literature Review: Switchgrass (Panicum virgatum L.)

Switchgrass

Switchgrass *(Panicum virgatum L.*) is a C-4 perennial grass, native to North America that evolved from maize approximately 23 million years ago (Parrish and Fike, 2005; Zhang and Maun, 1991). Switchgrass belongs to the family Poaceae (Gramineae), subfamily Panicoideae and the tribe Paniceae (Missaoui et al., 2005). This species is open pollinated and self-incompatible resulting in native populations that contain a wide range of diversity (Martinez-Reyna and Vogel, 2002). Populations of switchgrass have been found in locations with a variety of environmental and soil conditions nationwide. Switchgrass has also been found to grow successfully on marginal lands as well as in prairies, woods and marshes (Vogel 1996; Zhang and Maun, 1991). The overall success and biomass production obtained from the plants depend on how well the cultivar is adapted to the conditions of the particular area it is being grown. Evaluating the most productive cultivars in a specific region is necessary to accurately select the best cultivar for a particular soil type and climate, because different species of switchgrass are adapted to a wide range of different environmental conditions (Casler and Boe, 2003).

Switchgrass has a rhizomatous root system that can grow to a depth of 3.5 meters. The majority of the above ground switchgrass growth is composed of stems. The stems can send off tillers, which grow in clumps and can reach 0.5 to 3 meters in height (Parrish and Fike, 2005; Skinner and Adler, 2010). Switchgrass leaves are elongated and range in color from yellow- green to blue- green depending on the individual cultivar. Switchgrass produces triangular shaped panicles approximately 25cm in length at the end of the stems. The panicle contains groups of spikelets with each spikelet approximately 4-5mm in length. These spikelets contain the floret, which is generally red/ orange in color. When the floret is fertilized it is replaced by a seed approximately 2-3mm long, ovoid in shape, shiny and dark brown or green in color (Jensen and Boe, 1991). During the winter the switchgrass plant dies back to the crown and relies on energy reserves stored in the roots until the following spring.

Each switchgrass cultivar can be classified as either upland or lowland. The classification is based on morphological characteristics. There are also differences in chromosome number; however, these differences are not only between cultivars but within them as well. Switchgrass has a base chromosome number of nine (Lu et al., 1998). Upland cultivars morphological characteristics tend to be more similar to one another; although their genomes include tetraploid (4x= 36), hexaploid (6x= 54) and octaploid (8x= 72) types (Lu et al., 1998; Parrish and Fike, 2005). Upland cultivars tend to have thinner stems that grow in bunches and generally produce a lower biomass yield (Parrish and Fike, 2005). These cultivars generally have a longer root system, which could explain their higher drought tolerance and ability to maintain a higher CO_2 exchange and leaf water potential under drought stress. Upland cultivars are also able to recover quicker from drought stress than lowland varieties (Parrish and Fike, 2005; Wullshleger et al., 2010). All known lowland cultivars are tetraploids (4x= 36); however there is a wider range of variability in their characteristics (Parrish and Fike, 2005). Lowland cultivars tend to have thicker stems and wider bluish green foliage. Their root systems tend to be more expanded outwards instead of downwards (Parrish and Fike, 2005). The only genological significant difference that has been found between the two cultivars is a specific restriction site within the chloroplast genome of lowland cultivars that is not present in upland cultivars (Parrish and Fike, 2005).

To produce a unique cultivar, breeders collect a group of plants from a specific location and cross them with each other. If the resulting offspring is found to be uniform and contains desirable traits, the breeder can then register this population of plants as a unique cultivar (Parrish and Fike, 2005). The variability between the different ecotypes of switchgrass in different locations is quite significant because this species is self-incompatible. Cross pollination allows the plants to quickly adapt to the local climate, soil type and other environmental conditions. Wullshleger et al. (2010)indicates that there is most likely a correlation between growing season temperature and growth rate; however data comparing these variables has not yet been published (Wullshleger et al., 2010). The spring temperature before the growing season may also have a direct impact on the growth rate and yield (Wullshleger et al., 2010).

Little intensive breeding has been done with this crop because switchgrass is a native perennial adapted for the areas it is found. In addition, until more recently switchgrass had been used primarily as a forage crop for pasture kept livestock (Parrish and Fike, 2005; Sanderson et al., 1999). Any selection and breeding that has been conducted on this species in the past has been to improve its' quality as a forage crop. (Parrish and Fike, 2005) Requirements for forage crop production are somewhat different from those of bioenergy crops. Forage breeders' focus on the nutritional value of the plant breeding for raised levels of crude protein, minerals and nutrients while reducing the levels of cellulose and lignin. (Casler, 2006; Lemus et al., 2002; Wullshleger et al., 2010).

More recently researchers have become interested in evaluating this grass as a bioenergy crop. Breeding for a successful bioenergy crop focuses on elevated levels of cellulosic biomass including cellulose, hemicellulose and lignin while trying to reduce the levels of crude protein, nitrogen and minerals (Guretzky et al., 2011; Lemus et al., 2002). Breeding strategies for successful bioenergy crops also focus on uniform germination, uniform growth, to obtain an adequate return on investment (Wullshleger et al., 2010). However both forage and biomass crops require adequate stand establishment, persistently high yields, disease resistance and stress tolerance.

Current research into possible biofuel crops has started to move away from annual grain crops to perennial grasses. The production of ethanol from annual grain crops reduces the amount of petroleum required; however it still produces high levels of greenhouse gases; similar to those produced by gasoline (Guretzky et al., 2011). The conversion of cellulosic biomass from perennial grass crops has the potential to produce ethanol resulting in lower levels of greenhouse gas emissions (Guretzky et al., 2011). The use of perennial crops has the added benefit of improving soil conditions with more permanent root systems, decreasing erosion, improving local water quality and generally being more nitrogen efficient (Lemus et al., 2002; Nabity et al., 2012). Switchgrass is native to the United States, which provides the added benefit of having adapted to the local environment and widespread crop production would have less of an impact on the local environment than introduction of a nonnative species.

The ability to grow switchgrass on preserved grasslands and marginal lands is important because this allows the production of switchgrass to be conducted without displacing food and forage crops (Vogel, 1996). Marginal lands are areas that do not contain the highest quality soil and are highly erodible. In many cases they have not been planted or maintained for a number of years and contain a large population of weeds. Marginal lands generally have a lower soil nutrient content and lower fertility. These areas are not suitable for row crops since constant planting and harvesting can cause an increase in erosion. The low fertility would require more frequent or greater applications of fertilizer to meet crop requirements. Switchgrass has the capability to grow on marginal lands. The development of its root system and presence for multiple years can reduce soil erosion and increase the soils overall quality because this is a perennial crop (Vogel, 1996). Preserved grasslands are generally maintained to support the local wildlife, especially local bird populations (Murray et. al., 2003) Proper maintenance of these grasslands require cutting and removing some vegetation every year or so. Switchgrass would be optimal for these locations because it is a native perennial that has the highest production rates when harvested yearly. Therefore the proper maintenance of this crop mirrors the required maintenance of these preserved lands. This ability allows the crop to be grown by farmers and breeders even when field conditions are not prime or cannot be used for other purposes (Parrish and Fike, 2005; Vogel, 1996). Initially, growing switchgrass on marginal lands will most likely result in a reduction of overall biomass production; adequate biomass production may require higher fertilization applications until the soil quality has been significantly improved (Parrish and Fike, 2005).

Establishment Challenges

Breeders and farmers have encountered many challenges while trying to grow switchgrass as a bioenergy crop. One of the most complex and challenging obstacles is seed dormancy (Adkins et al., 2002; Parrish and Fike, 2005; Shen et al., 2001). There are 3 main types of dormancy; primary, secondary or residual and dormancy reversion. Primary dormancy occurs immediately after harvest and can be removed with a cold treatment or stratification. Secondary dormancy occurs when the seed is still dormant after a cold treatment and requires a chemical treatment. Dormancy reversion occurs when a stratified seed is re-dried before it is planted (Sarath and Mitchell, 2008). Switchgrass seeds do not have uniform germination immediately after harvest; this trait is beneficial to the plant in its native environment, especially when conditions are unfavorable for seedling growth. A staggered germination rate increases the chance of some seedling survival because not all seeds will germinate when these unfavorable conditions are present. Some of the seeds will germinate later when conditions may be more conducive to survival. For large scale crop production; however, uniform germination is vital. Since dormancy can be due to a number of factors finding an effective seed treatment and achieving uniform germination can be difficult.

One of the most common seed treatments is seed chilling which exposes the seed to a lower temperature for a set period of time, generally the seed is stored at 4^{o}C for approximately 14 days (Beckman et al., 1993). This process was developed to mirror conditions in the natural environment (Adkins et al., 2002). In nature the seeds are released from the plant in the fall and remain dormant throughout the winter before germinating in the spring. Cold treatments have had the greatest effect on increasing germination and emergence rates when compared to other treatments including wet treatments (Beckman et al., 1993; Hsu et al., 1985). Another seed treatment, which can be done concurrently with seed chilling, is ripening, which requires the seeds be held in storage for a year or more before planting (Parrish and Fike, 2005). Soaking switchgrass seeds in gibberellic acid has been shown to cause the seed to release proteolytic and hydrolytic enzymes that provide the seed with nutrients; this can also cause the seed to break dormancy (Adkins et al., 2002).

Removing the seed coat through acid or mechanical scarification or hormone treatment has been shown to reduce dormancy (EPA, 2010; Jensen and Boe, 1991; Parrish and Fike, 2005). Mechanical scarification partially removes the seed coat, which allows for increased water uptake and gas exchange within the seed. This process has been found to increase germination up to 39% in some switchgrass varieties (Jensen and Boe, 1991). Acid scarification involves soaking the seed in certain chemical treatments. In one experiment researchers soaked seeds in H_2SO_4 for approximately 5 minutes and then rinsed the seeds for another 5 minutes; which increased the overall germination rate (Haynes et al., 1997). Pre-chilling seeds in a KNO_3 solution for approximately 2 days before planting is another method that has been shown to increase germination (Haynes et al., 1997).

Stratification is the technique of moistening and cooling seed to reduce dormancy. This process requires the seeds to be stored in a cool moist environment for a number of days before being planted. Although this process does increase germination the seeds must remain moist when planted. Drying and remoistening the seeds can cause re-dormancy to occur and reduce germination rates by 50% compared to stratified seed that has not been re-dried (Shen et al., 2001). These treatments require more costly seed preparation and the use of more chemicals and equipment.

Another variable affecting seed germination is soil temperature at time of planting. It was found by Hsu et al. (1985) that if the soil was warmer at the time of planting germination rates increased. The optimal temperature for switchgrass seed germination is between 25^{o}C and 35^{o}C (Parrish and Fike, 2005). Planting switchgrass seeds later in the spring, when temperatures have risen, can improve germination rates due to dormancy; however, this also provides greater competition with native weeds in the field.

Weeds can prove tough competition for emerging switchgrass seedlings (Rinehart, 2006; Smart and Moser, 1999). Weeds that tend to emerge around the same time as switchgrass compete for space, nutrients and water. Annual weeds are the most competitive because they tend to grow at a faster rate and impede both switchgrass development and establishment (Parrish and Fike, 2005). Research had shown that glyphosate applications before planting and the use of a no-till planter can significantly reduce weed competition and increase switchgrass establishment (Parrish and Fike, 2005; Sanderson et al., 2004).

Water availability has been identified as one of the most important factors in switchgrass establishment (Parrish and Fike, 2005). Although upland varieties have been found to be more drought tolerant, chronic drought causes a loss in biomass in all varieties and extreme drought can cause complete crop loss (Parrish and Fike, 2005; Sanderson et al., 1999). Initial establishment requires adequate water availability and soil moisture levels to be maintained. In marginal lands or fields remote from established crop lands water transport may be an issue. Although this is a low input crop, initial water requirements may restrict establishment to more accessible fields and areas.

Currently there are very few insect pests and diseases that cause significant economic damage to switchgrass (Parrish and Fike, 2005). With an increase in production of this crop as a monoculture, there will be an inevitable increase in crop pests and diseases that attack the crop. With increased crop production pests and diseases tend to proliferate and begin to have a significant impact on biomass yields. As with any crop, an increase in overall switchgrass production will result in new pests and diseases.

Nutrient Requirements

Switchgrass establishment also requires nutrient management. Although considered a low- input crop, fertilizer applications are required after each harvest or before the beginning of each growing season. In a research trial conducted in Iowa the recommended application of nitrogen fertilizer was approximately 56kg/ha (Lemus et al., 2008). Recommended soil phosphorus levels for switchgrass are approximately 12 to 15mg/kg soil (Lee et al., 2007). Nitrogen fertilizer applications at this rate increased biomass production approximately 20% compared to non- fertilized plots. Although higher nitrogen application rates can increase biomass production in switchgrass, the increase is non- linear and the additional cost of the fertilizer may outweigh gains from additional biomass harvested (Lemus et al., 2008). Vogel et al. (2002) determined that the optimal rate for nitrogen fertilizer was 120kg/ha in the Midwest USA (Vogel et al., 2002). At this rate, nitrogen application and nitrogen uptake by the switchgrass was balanced so that residual nitrogen did not remain in the soil. This reduced the amount of erosion and nitrogen runoff leaving the field. Soil samples taken from the research plots indicated higher rates of fertilization resulted in an overall increase in soil nitrogen (Vogel et al., 2002). The frequency and timing of fertilization treatments is also important. There is a general consensus in the experiments conducted by Lemus et al. (2008) and Vogel et al. (2002), that the optimal fertilization period is once annually around May or June of each harvest year. The experiment conducted by Lemus et al. (2008) also found a positive cumulative effect on biomass yield over the span of the four years the experiment was conducted. The number and timing of harvests each year also affects the amount of nitrogen fertilizer required by the switchgrass crop. Results from one experiment indicated that an annual harvest conducted after the plants had reached full maturity and the panicle had fully emerged, resulted in the greatest biomass yields (Vogel 2002). Waiting to harvest after the first killing frost increased the overall production and stand quality of switchgrass crops (Lee et al., 2007). Harvesting after the first killing frost not only increases biomass but also reduced the amount of nitrogen removed from the plants. This is because during the fall, as the plant approaches dormancy, plant nutrients; such as nitrogen, are transported from the foliage of the plant and stored in the crown (Parrish and Fike, 2005). Harvesting at other times of the year does not take advantage of this biological process and results in removal of a larger amount of nitrogen than necessary. Additional harvests throughout the season will also result in a reduction of the total amount of biomass collected and require a greater amount of nitrogen applied to the soil and a greater number of nitrogen fertilizer applications.

To further reduce the cost of switchgrass crop production, a number of studies have been done to evaluate the effectiveness of organic and waste material applications on the growth and biomass production of switchgrass. If an effective alternative nitrogen source can be determined the use of more expensive synthetic nitrogen fertilizers can be diminished or even eliminated, this would further reduce the cost of production. A lower cost would encourage more growers to become interested in growing this crop and increase the economic gain achieved by this crop.

Waste materials; such as solid waste and sewage sludge, is another option that has been evaluated by a number of researchers. Sewage sludge is derived from treated municipal wastewater (Warman and Termeer, 2005). This material contains a significant amount of nitrogen and can be used as a nutrient source for corn and forage crops (Warman and Termeer, 2005). Sewage sludge must be treated before it can be used as a soil amendment due to the instability and the potentially harmful microorganisms present (Tester, 1989). Composting sewage sludge is an effective method for stabilization. One study evaluated the effect of compost composed of treated sewage sludge and woodchips on the growth of warm season grass. In this study, field plots amended with a one-time fertilizer application and compost treatment resulted in higher biomass yields than those that only received a fertilizer application. An annual nitrogen application of 200kg/ha was equivalent to the 60Mg/ha compost application rate. The compost amendments provided a more long term nitrogen source since the synthetic fertilizer started to leach from the soil before the grass had reached full maturity (Tester, 1989). Research indicates that an initial application of fertilizer and sludge compost followed by annual sludge compost applications significantly increased biomass yields of forage grasses compared to unfertilized control plots (Shiralipour et al., 1992; Warman and Termeer, 2005). The initial application requires a quick release synthetic fertilizer because this is an immediate source of nitrogen for the seedlings; the compost provides a slow-release more long-term source of nitrogen. Organically amended soils were found to contain higher levels of nitrogen after the second year of treatment, compared to the fertilizer amended plots (Warman and Termeer, 2005). This indicates that organic substances could be used to provide crops with at least a portion of the nitrogen they require, which could reduce fertilizer costs. Application of this waste material is also able to increase the amount of organic matter in the soil, which increases the overall soil quality and fertility; which in turn increases the availability of nutrients to the crop (Shiralipour et al., 1992). Another study utilized a sterilized material they termed “Fluff” formed from the organic components of municipal solid waste. This material was found to be effective at reducing weed competition and allowing native grasses to establish and grow (Busby et al., 2006). The percent of switchgrass establishment, composition and density was directly proportional to the amount of material applied to the area (Busby et al., 2006). This indicates that sewage sludge materials can be used both as a nitrogen source and method for weed suppression in switchgrass production.

Another material that has been evaluated for use as a nitrogen source for biomass crops is manure compost. Manure can accumulate quickly on farms, so having an alternative use for this waste product could reduce excess nutrient build up (Butler and Muir, 2006). Using composted material as a nutrient source for annual crops is not effective because the nutrients are not readily available and they are released at lower levels (Butler and Muir, 2006; Helton et al., 2008; Lynch et al., 2004). These same characteristics make manure compost an appealing option for perennial crops, since they can benefit from a slow- release source that extends nutrient availability and reduces the rate of nutrients leaching from the soil (Butler and Muir, 2006; Lynch et al., 2004). The main nutrient provided by manure compost is nitrogen, however it also a source of phosphorus and potassium (Butler and Muir, 2006). In a study done by Lynch et al. (2004) application of dairy manure compost increased the cumulative biomass yield of a grass monocrop compared to the unfertilized control. Liquid manure resulted in a 29.4% increase and composted dairy manure increase yields by only 15.1% (Lynch et al., 2004).

Application of manure compost also increases the organic matter in the soil further improving the soil quality (Butler and Muir, 2006). Increased organic matter can improve the soil pH, nutrient content, reduce erosion and increase the water holding capacity. A study by Lee et al. (2007) determined that manure applications increased the percent of switchgrass present compared to plots treated with synthetic nitrogen fertilizer. Weed density was decreased in plots treated with manure compared to plots treated with synthetic fertilizer (Lee et al., 2007). Overall, initial applications of synthetic nitrogen applications increase weed biomass, whereas manure applications increase switchgrass biomass. In a study conducted by Helton et al. (2008) grass crop dry mass production was increased with increased application rates of dairy manure compost compared to the unfertilized control. Although the use of synthetic fertilizer containing nitrogen resulted in greater biomass yields; using organic compost treatments have the added benefits of increasing the soil quality, improving the soil composition and providing a steady available source of nitrogen over a long term period that is less susceptible to leaching from the soil. A quick release synthetic nitrogen fertilizer can be used in addition to an organic amendment to further optimize dry mass yields. (Helton et al., 2008) Application of synthetic phosphorus and potassium resulted in no significant increase in yield (Helton et al., 2008).

Plant waste compost is another readily available nutrient source. Yard waste compost is produced by most homeowners and includes grass clippings, leaves and small branches. Crop residue compost is a ‘waste product’ produced by farms and is composed of undesirable plants and plant parts form the crops they grow. These types of compost are another source of slow-release nitrogen, as well as other macro and micronutrients; which are ideal for perennial crops including switchgrass (Lynch et al., 2004; Singer et al., 2006). Both of these products are used as soil amendments on agricultural lands producing positive results in crop dry mass production. In an experiment conducted by Lynch et al. (2004) harvested dry mass yields from high application rates of crop residue compost matched yields from inorganic fertilizer applications over a two year period. Researchers determined that annual application of compost amendments are adequate nutrient sources for high yielding crops including perennial grass forages. Research conducted by Singer et al. (2006) evaluated the use of compost on highly erodible marginal lands, for the production of native perennial plant establishment. Surface applied compost proved to be an effective weed control mechanism for annual grass weeds. Both surface applied and incorporated compost methods increased the overall biomass present in the plots (Singer et al., 2006). Composts improve marginal soil quality by increasing the organic matter present which increases the cation exchange capacity, water retention capacity and nutrient content (Lynch et al.,2004; Singer et al., 2006). Overall, the use of compost as a soil amendment is highly beneficial to soils; however long term use of composts on highly fertile soils must be closely monitored to prevent the accumulation of excess phosphorus and potassium in the soils (Lynch et al., 2004).

The Acai berry is a fruit that grows native in Brazil and other parts of Central and South America. This is a palm plant that produces dark purple berries. Recently this fruit has become popular in the United States (Mertens-Talcott et al., 2008). Since approximately 90% of the berry is made up of the seed, local companies that produce acai juice products are left with a large amount of 'waste product.' This waste produce has been used as a compost and fertilizer as it contains many nutrients and minerals. Access to large amounts of this compost could be used to fertilize perennial crops and reduce the requirements for synthetic fertilizers.

Requirements for local production

For switchgrass to be available for large- scale bioenergy production the crop must be accepted and grown by farmers nationwide. In addition farmers prefer to gain a larger profit from perennial crops versus annual crops, because there is less flexibility in land use (Bocqueho and Jacquet, 2010; Paulrud and Laitila, 2010). The risk of tying up land for an extended period of time is only outweighed if the profit gained is significantly greater or guaranteed (Bocqueho and Jacquet, 2010). Many experimental techniques have produced desirable results, including increased yields, which should translate to increased profits. Unfortunately, many of the experimental techniques used are not realistic options for farmers that must optimize crop yields while simultaneously minimizing material and production costs.

One major concern of farmers is cost of seed and the seeding rates (Hipple and Duffy, 2002). If the materials are too expensive this can be cost limiting and have a major impact in the profitability of growing switchgrass. These concerns further emphasize the importance of acquiring seed with a high germination rate. This will reduce the seeding rates and the amount of seed that must be purchased by the farmer for successful stand establishment. The best methods for increasing germination would be those that not only result in the greatest germination but also incur the least cost to the farmer. Both seed chilling and ripening significantly increased the germination rate of switchgrass seed (Beckman et al., 1993, Hsu et al., 1985; Parrish and Fike, 2005). This could be accomplished by buying the seed a couple of years in advance and storing it in a cool dry place where the temperature fluctuates moderately. The methods of seed scarification require additional equipment the farmer may not have access to, costly chemicals and additional labor the farmer may not be able to afford. The method of stratification requires the farmer to plant the seeds while they are still wet, this cannot be done with standard seeders and may require the purchase of new seeding equipment. These requirements can be cost prohibitive and cause an unnecessary reduction in the farmers' profit. For these reasons seed scarification, stratification and chemical soaks are not feasible for large- scale switchgrass production (Parrish and Fike, 2005). Seed chilling and ripening are the most cost-effective and least labor intensive solutions for achieving uniform switchgrass germination on a large-scale.

Determining the best time to plant is also important in ensuring the success of stand establishment. If the seed is planted too early and the soil is too cool germination rates may be lower. If the seed is planted too late in the season annual weed species may out compete the switchgrass seedlings, reducing survival rates for the following year (Rinehart, 2006; Smart and Moser, 1999). The optimal temperature for germination depends on the cultivar selected and the region in which it is planted.

Profit is an additional requirement farmers have for growing a new crop (Hipple and Duffy, 2002). If farmers are not going to make more money by producing a new crop they will have little motivation to switch from the crops they are already growing. This requirement makes choosing the cultivar that is best adapted for a particular region extremely important. If a specific cultivar is known to produce a greater dry mass yield this will provide the farmer with a greater profit and more incentive to start growing the crop.

Farmers prefer crops that require less weed management, because this can also cut into their profit (Hipple and Duffy, 2002). Chemical pesticides can be expensive and application requires both equipment and fuel use. Development of alternative weed management techniques can reduce pesticide requirements and any associated costs. In recent studies, it was determined that compost was able to reduce weed growth in some environments when trying to establish native perennial grasses (Lee et al., 2007). Application of compost can be a cheap alternative to applying pesticides and reduce excess accumulation of these ‘waste materials’ on farms. Compost applications can also provide the nutrients required by the crop.

Synthetic fertilizer is expensive and nutrient requirements can impact grower preferences. Switchgrass is considered a low- input crop; however, fertilizer applications are recommended after each harvest or before each growing season (Lemus et al., 2008). Compost amendments could be used to reduce or eliminate synthetic fertilizer requirements. These materials may be less costly than commercial fertilizer. The savings from using these alternative nutrient sources would be maximized if the products could be obtained locally or from the farmers own property. Some alternatives include solid waste from municipal or industrial sources, sewage sludge, manure compost, liquid manure and plant waste compost. While municipal and industrial solid waste may be acquired cheap the level of processing required to produce a safe product for application must be taken into consideration. The costs of treating and composting sewage sludge could make it cost- prohibitive, unless these costs are paid for by the municipality, instead of the farmer. While liquid dairy manure resulted in a greater significant increase in biomass production than compost manure, this product may not be available or easily used by local farmers and it requires special equipment for application (Lynch et al., 2004).

Objectives

The objectives of this research were to determine: 1) the cultivars able to establish best in the local region and produce high dry matter yield in central New Jersey; 2) the optimal planting date for the quickest rate of germination in this region for switchgrass; 3) the effect of locally available compost and nutrient amendments on switchgrass establishment and dry matter yield; 4) the effect of rototilled versus no-till planting methods on switchgrass emergence and stand establishment.

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Chapter 2: Establishment, Growth Characteristics and Yield of Switchgrass (*Panicum virgatum L.*) Cultivars in NJ

ABSTRACT

Switchgrass (*Panicum virgatum L.*) production for bioenergy can be optimized by using the cultivars most adapted to the specific region in which they are being grown. Small- scale switchgrass production on farms in the Northeast would benefit from planting a bioenergy crop to offset energy costs. Five different cultivars; two upland, ‘Carthage’ and ‘High Tide’ and three lowland, ‘Alamo’, ‘Timber’ and ‘Kanlow’, were evaluated for their overall establishment, growth and dry biomass yields in the Northeast. The trial was established in July 2010 in North Brunswick, NJ. Plots were evaluated for frequency of emerged plants in 2010. Plots were further evaluated for stand survival, stand quality, heading dates, anthesis dates, plant height, lodging, dry matter yield and dry matter content in 2011 and 2012. ‘Alamo’, ‘Carthage’ and ‘Kanlow’ had significantly $p < 0.05$ greater emergence than ‘Timber’ and ‘High Tide’. There was no significant difference in plot quality between the different cultivars in either year. There was no significant difference in yield for the first harvest year. In the second harvest year ‘Carthage’ had significantly greater ($p < 0.05$) yields than ‘Alamo’, ‘Timber’ and ‘High Tide’, while ‘Kanlow’ had significantly greater ($p < 0.05$) yields than ‘High Tide’. ‘Carthage’, ‘Kanlow’ and ‘High Tide’ yields significantly increased ($p < 0.05$) from the first to the second harvest year. This was explained by the improvement in stand quality.

INTRODUCTION

Switchgrass (*Panicum virgatum L.*) is a warm season perennial grass native to North America and adapted to many climates and environmental conditions (Casler and

Boe, 2003). Because it is perennial, costs associated with planting and establishment need only be incurred once a decade, because the crop can be harvested for ten years without significant loss in biomass production (Duffy and Nanhou, 2002). The perenniality of switchgrass also improves the quality of soil over time; by increasing organic matter and improving water quality by reducing runoff (Duffy and Nanhou, 2002). It also provides a natural wildlife habitat (Casler and Boe, 2003) for small mammals and birds.

The use of switchgrass for bioenergy production has been considered by many organizations including the Department of Energy and the Environmental Protection Agency. The potential benefits for small farmers to offset energy costs could be substantial if they are able to grow the crop in marginal locations without displacing their traditional crops (EPA(1), 2010; Mitchell *et al*. 2008).

Switchgrass cultivars can be classified as either upland or lowland. Upland cultivars tend to have lower biomass yields, but have a longer root system allowing for greater drought tolerance (Parrish and Fike, 2005). Lowland cultivars tend to produce a greater biomass yield under optimal conditions; however they have shallower, more expanded root systems (Parrish and Fike, 2005). The wide diversity of cultivars currently available provides numerous options for growers; however, not all cultivars are equally productive in all locations (Casler et al., 2004)

Although switchgrass can be found across the North American continent; individual populations have evolved and adapted to different regions. Various environmental conditions including precipitation, temperature, soil type and altitude all affect plant phenotypes (Casler et al., 2006). Casler et al. (2007) found that the latitude of a cultivars' original location had a significant impact on the biomass production.

Therefore, when selecting switchgrass cultivars to evaluate in a trial, the location of origin is particularly important. Lemus et al. (2002) evaluated 20 different switchgrass populations for overall plant quality and biomass yield in southern Iowa. They found that a highly recommended upland cultivar grown in central Iowa, ‘Cave-In- Rock’ did not produce as well as two lowland cultivars ‘Alamo’ and ‘Kanlow’ in the lower quality soil present in Southern Iowa (Lemus et al., 2002). This emphasizes the need for evaluations to be done in each potential switchgrass crop location to determine the best suited cultivar for the unique conditions of that particular location.

Weather is extremely variable in New Jersey and winters can be warm and mild or cold and harsh; precipitation during the growing season is a major variable that tends to vary greatly between years. Depending on the winter conditions and amount of precipitation during the growing season, lowland or upland cultivars may produce more favorable results. If the winters are mild or the growing season is wet lowland cultivars may produce higher biomass yields. If the winters are cold or drought conditions occur during the growing season then the upland cultivars may produce greater biomass yields (Parrish and Fike, 2005; Rinehart, 2006).

Marginal lands and disturbed soils are areas that contain low quality soil, which can be highly erodible, have low fertility, contain few nutrients and organic matter, have low water retention rates or have a low cation exchange capacity (Sanderson *et al*. 1999, Singer *et al*. 2006). Although many researchers have evaluated switchgrass in different locations throughout the United States on both fertile and marginal lands, only a few studies have evaluated cultivars adapted for low maintenance locations in the Northeast and more specifically New Jersey (Bonos et al., 2011). As of 2010 there were approximately 10,300 farms in New Jersey alone, which took up over 296,816 ha of land. Of this area approximately 21,855 ha are designated pasture lands (USDA, 2011). These farmers could benefit from knowing the cultivars that perform best under local environmental conditions. The objective of this experiment was to compare the establishment, growth characteristics and biomass yield of several switchgrass cultivars grown in central New Jersey under low input conditions.

MATERIALS AND METHODS

Field preparation and design

The field used for this study was a former potato (*Solanum tuberosum*) field that had not been planted in for over ten years. The soil was a Woodstown loam with a 0%-2% slope, a pH of 6.6 and approximately 3.41% organic matter. The main vegetation present prior to planting, included goldenrod (*Solidago altissima*), thistle (*Silybum marianum*), and many annual grass species. The field was prepared a year prior to planting. In July 2009, the field was mowed with a rotary mower leaving a stubble height of approximately 15 centimeters and was then plowed. A cultipacker was then used to level the soil and reduce aggregate size. The soil was then rototilled in preparation for planting. A glyphosate application was applied in August 2009 at a standard rate of 1.12 kg ai ha^{-1}, two weeks before planting (Miesel, 2012). A cover crop of cereal rye (*Secale cereale*) was planted in September 2009. This rye straw was cut and baled in June 2010. A second glyphosate application was applied in July 2010 at standard rates.

The field was organized in a randomized complete block design with four blocks and four replications per cultivar. A 6.4 m border row of Carthage was planted around the entire trial area. The plots were planted on 14 July 2010 with a Great Plains No- Till

Planter model number 1006 (Great Plains Manufacturing Inc. Salina, Kansas) because no- till methods have been used successfully in switchgrass establishment (Rinehart, 2006). Each plot was 6.4 m wide and 45.7 m long or approximately 0.029 ha for a total plot area of approximately 0.62 ha.

Plots were irrigated during establishment during the months of July and August to promote successful establishment. The total amount of water used to irrigate the trial was 16.07 m^3, this equates to approximately 25.95 m^3 ha^{-1}. Rainfall was adequate in late August so supplemental irrigation was terminated.

Plant material and treatments

Five different switchgrass cultivars were evaluated in this study. Seed of ‘Carthage’, ‘Timber’ and ‘High Tide’ were obtained from the USDA- NRCS Cape May Plant Materials Center and ‘Alamo’ and ‘Kanlow’ from Ernst Conservation Seed. The cultivars chosen included 2 upland cultivars (‘Carthage’ and ‘High Tide’) and 3 lowland cultivars (‘Timber’, ‘Kanlow’ and ‘Alamo’). These cultivars were chosen because they had been grown in the region and were shown to produce adequate yields in New Jersey (Cortese and Bonos, 2012) ‘Timber’ and ‘Kanlow’, 2 of the lowland cultivars selected were the top performers in an experiment conducted in New Jersey in 2006 (Miller, 2009). ‘High Tide’ was the highest producing upland cultivar in the experiment (Miller, 2009). ‘Timber’ was determined to be well adapted to New Jersey and capable of growing in soils with sub-optimal moisture conditions. The ‘Timber’ and ‘Carthage’ cultivars both originated from North Carolina; however these cultivars have been grown multiple years in New Jersey at the Cape May Plant Materials Center and the germplasm from this locations has become adapted to the New Jersey climate and growing conditions (Miller, 2009; Miller, 2006). These cultivars tend to produce higher biomass yields in the northeast compared to cultivars originating from the Midwest (Cortese and Bonos, 2012; Miller, 2006). Although ‘Kanlow’ is considered a southern ecotype its biomass production was found to be statistically similar to ‘Carthage’ in a recent northeast study (Cortese and Bonos, 2012). ‘Alamo’ is a cultivar that originated from Texas; but can exhibit high yields in mild, wet years.

As per the distributers label, each switchgrass cultivar varied in germination percent. Carthage ranged from 85% to 98%, Kanlow ranged from 75% to 83%, Timber ranged from 83% to 91%, Alamo ranged from 66% to 75% and High Tide ranged from 70% to 76%. The seed was planted at a recommended rate of approximately 12.8 kg ha^{-1} of pure live seed (Rinehart, 2006).

Field Maintenance

Because of high weed pressure from annual grassy weeds, the field was mowed to a height of 0.3 m on 25 May 2011. This process helped to reduce weed competition without harming the switchgrass and eliminated the need for chemical herbicides. The timing of the cutting, in the late spring, reduced the total amount of annual weed biomass growing in the field and promoted dieback of most annual species because of the warmer temperatures.

2,4-D was sprayed at the rate of 1.12 kg ai ha^{-1} on 3 June 2011 to further inhibit broadleaf weed competition. Borders between individual plots were mowed weekly during the growing season using a standard push lawn mower (Craftsman, Hoffman Estates, Illinois).

In the summer of 2011 there was a high infestation of mile- a- minute weed (*Persicaria perfoliata L.*) in the plots, which was manually removed. No further problems were encountered with this weed through the summer of 2012.

Data Collection

Plots were evaluated for emerged seedlings in 2010. Plots were further evaluated for stand survival, stand quality, heading dates, anthesis dates, plant height, lodging, dry matter yield and moisture content in 2011 and 2012.

Emerged seedling frequency and survival ratings were obtained by measuring the number of emerged seedlings within a frequency grid as outlined by Vogel and Masters (2001). The grid is 0.56 m^2 with 25 equally sized cells. A record is taken of how many cells contain at least one emerged seedling. Four ratings were taken randomly in each plot so that a total of 100 cells were counted. The frequency of emerged or survived seedlings is calculated by adding the number of cells containing at least one plant and dividing by the total number of cells (100). This calculation determines the frequency of seedlings within the plot. To determine the approximate plant density in a 1 m^2 area, the number of cells out of 100 containing emerged plants, within each plot area were added together and multiplied by 0.4 (Vogel and Masters 2001). The number of emerged seedlings was estimated approximately one month after planting on 13 August 2010. Survival ratings were taken 22 June 2011 and 12 May 2012.

Plot quality ratings were taken using a visual rating system to estimate the percent of the plot covered by switchgrass foliage where 1 represented approximately 10% of the plot and 10 represented 100% of the plot. Quality ratings were taken 1 June, 22 August, and 5 November 2011 and 22 June and 5 July 2012. Heading dates were recorded between 17 August to 2 September 2011 and 5 July to 2 Aug. 2012; when panicles first became visible. Anthesis dates were recorded between 7 September to 27 September 2011 and 29 July to 28 Aug. 2012; when pollen was present on 50% of the panicles in the plot.

Plant height was recorded 5 Nov. 2011 and 16 Nov. 2012. Plant height was measured from soil surface to the top of the panicles in three random locations within each plot; an average of these measurements was calculated for each plot.

Lodging ratings were determined using a visual rating system where 1 represented a plot with 100% completely erect plants, 3 represented a plot with plants angled at 45^{o} to the soil surface and 5 represented a plot with 100% completely lodged plants; lying flat on the soil surface. Ratings were taken on 5 Nov. 2011 and 16 Nov. 2012 after anthesis. In the first year ratings were taken only 2 weeks after a snowstorm and therefore had lower ratings compared to the second year where the plots were allowed additional time to recover before ratings were taken.

Plots were harvested 18 Nov. 2011 and 11 Jan. 2013. A 0.914 m by 6.1 m sample of each plot was cut with a sickle bar mower (BCS 853, Abbiategrasso, Milano, Italy) leaving approximately 0.15 m stubble. The samples were weighed to get a total fresh weight. Two subsamples; approximately 500g each, were collected from each sample, weighed and then dried in a forced air drier at approximately 38^{o}C for at least 1 wk and weighed again to determine the dry matter content of the total sample.

Statistical Analysis

This experiment was arranged in a randomized complete block design with four replications per cultivar. There were five different cultivars present for a combined total of twenty plots. Data was collected over two growing seasons and was analyzed using the Statistical Analysis System SAS 9.2 software for windows. The procedures used to analyze the data included the standard Analysis of Variance (ANOVA) procedure with LSD and PROC CORR analyses.

RESULTS AND DISCUSSION

Significant cultivar differences were observed for seedling emergence ($p<0.01$), survival ratings ($p<0.01$), plant height ($p<0.01$), dry matter yield ($p<0.05$) and percent moisture content ($p<0.001$). Harvest year was significant for dry matter yield ($p<0.05$) and dry matter content ($p<0.01$). Heading and anthesis dates were highly correlated. A positive correlation between plant height and heading date as well as plant height and anthesis date was also found. There was also a positive correlation between plant height and lodging the first harvest year. Plant height was positively correlated to harvest yield.

Seedling emergence; taken 13 August 2010, thirty days after planting, revealed significant differences in seedling emergence frequency between different cultivars. ‘Carthage’, ‘Alamo’ and ‘Kanlow’ had significantly greater ($p< 0.01$) seedling emergence than ‘Timber’ and ‘High Tide’ (Figure 1). Different cultivars and seed lots may be subject to a greater or lesser amount of seed dormancy which could influence germination and emergence rates. Emergence ratings were taken 30 days after planting to allow adequate time for the majority of the seed to overcome dormancy. In a field experiment by Shaidaee et al. (1969) researchers found switchgrass reached a maximum emergence rate of 70% 21d after planting. Soil conditions during the time of planting were warm and dry so supplemental irrigation was added. Although significant differences were seen early on in seedling emergence rates, these results did not correlate with later ratings done on percent plot quality. It is possible that increased plant vigor or delayed germination of additional seed allowed cultivars such as ‘Timber’ and ‘High Tide’; which had lower initial seedling emergence to catch up to the earlier growing cultivars later in the growing season. This was seen in a study done by Shaidaee et al. (1969), where younger seed lots were slower to emerge, but had higher percent emergence by the end of the trial.

‘Carthage’ and ‘Alamo’ had had significantly higher stand survival than ‘Timber’ and ‘High Tide’ ($p< 0.01$). ‘Kanlow’ and ‘Timber’ had significantly higher stand survival than ‘High Tide’ ($p< 0.01$) (Figure 2). Later season visual ratings of stand establishment did not result in any differences between cultivars.

Visual estimates of percent cover of switchgrass taken in 2011 and 2012 indicated that there were no significant differences between the five cultivars. Ratings were taken June 2011 and July 2012 (data not shown). Percent plot cover determines the amount of area covered by the switchgrass plant foliage in the plot area, but does not consider plant height, plant quality or plant stem distances. As plants grow taller this method can be difficult to use in larger plots as patches or empty areas toward the middle of the plot, are less likely to be spotted. Lemus et al. (2002) found that the highest yielding cultivar had large patches within the plot area with no switchgrass plants. Stand thinning can occur, resulting in plot areas with larger plants in lower density stands (Lemus et al., 2002).

In 2011 heading dates ranged from 209 and 225 d for all cultivars while anthesis dates ranged from 230 to 250 d. In 2012 heading dates ranged from 187 to 215 d for all cultivars while anthesis dates ranged from 211 to 241 d. As expected heading dates and anthesis dates were highly correlated ($r^2 = 0.83$ $p < 0.01$). ‘Alamo’ had significantly later heading dates than ‘High Tide’ and ‘Carthage’ ($p < 0.05$). ‘Timber’ and ‘Kanlow’ had significantly later heading dates than ‘Carthage’ ($p < 0.05$). ‘Alamo’, ‘Kanlow’ and ‘Timber’ had significantly later anthesis dates than ‘Carthage’ and ‘High Tide’ ($p < 0.01$) (Table 1). Lowland cultivars were later maturing than upland cultivars as determined by Sanderson et al. (1998). Casler et al. (2007) also determined a direct correlation between heading date and latitude of origin.

Generally when a plant matures earlier its growth rate will decline more quickly. Therefore, the expectation is shorter plants with earlier heading/ anthesis dates and taller plants with later heading/ anthesis dates. In year 1 plant height was positively correlated to heading dates ($r^2 = 0.62$ $p < 0.05$) and anthesis dates ($r^2 = 0.52$ $p < 0.05$) although, not strongly correlated. In year 2 plant height was positively correlated to heading dates ($r^2 = 0.64$ $p < 0.05$) and anthesis dates ($r^2 = 0.70$ $p < 0.01$). Cortese and Bonos (2012) found that plant height was positively correlated to heading date.

Average plant height for each cultivar was calculated for 2011 and 2012 before harvest. For 2011 ‘Timber’ was significantly ($p < 0.01$) taller than ‘Alamo’, ‘Carthage’ and ‘High Tide’. ‘Kanlow’ was significantly ($p < 0.01$) taller than both upland cultivars. For 2012 ‘Timber’, ‘Kanlow’ and ‘Alamo’ were significantly ($p < 0.\ 01$) taller than both upland cultivars (Figure 3). The difference between years could have resulted from the fact that the first year data was taken during establishment and switchgrass stands had not yet reached maturity (their full potential). These results are consistent with the characteristics of upland and lowland cultivars. Lowland cultivars are known to be taller and later maturing than upland cultivars (Lemus et al., 2002).

Average lodging rates for each cultivar were calculated before harvest in 2011 and 2012 (Figure 4). For 2011 cultivars had average ratings between 3.5 and 4.5 for lodging, which is between 45^{o} and parallel with the ground. ‘High Tide’ had significantly ($p < 0.01$) less lodging than all other cultivars. For 2012, there was no significant different in average lodging ratings by cultivar. Over the span of the two harvest years, there was no significant difference in average lodging ratings by cultivar. These results are consistent with the research done by Lemus et al. (2002), which observed no significant differences between plant height and lodging. During the first harvest year plant height was moderately positively correlated to lodging ratings ($r^2 = 0.47$ $p < 0.05$) however, there was no correlation for the second harvest year. Lodging ratings for ‘Alamo’, ‘Kanlow’, ‘Timber’ and ‘Carthage’ were significantly lower in the second year compared to the first ($p < 0.05$). This could have resulted from the fact that in 2011 the ratings were taken less than a week after an early snowstorm; while the ratings taken in 2012 were not taken until after the field had a chance to recover from an October snowstorm. All switchgrass cultivars exhibited almost complete recovery from lodging due to snowfall in both years. Lemus et al. (2002) also determined that no plots exhibited significant lodging that would hinder harvesting in their experiment.

Total average dry matter yields of harvested samples for each cultivar were calculated for the first and second harvest years. No significant differences were observed between individual cultivars in the first year. For the second harvest year, ‘Carthage’ had significantly higher yields than ‘Alamo’, ‘Timber’ and ‘High Tide’. ‘Kanlow’ had significantly greater yields than ‘High Tide’ (Figure 5). The second harvest year had significantly greater yields than the first harvest year. This data is consistent with research done by Fike et al. (2006) where switchgrass stands did not produce consistent yields until three to five years after establishment.

In year one, 2011, ‘Carthage’ and ‘High Tide’; the 2 upland cultivars, had the lowest average yields; however by the second year ‘Carthage’ had significantly greater yields than ‘High Tide’. Plant height was moderately positively correlated to harvested yield ($r^2 = 0.46$ $p < 0.05$). This data correlates with research done by Lemus et al. (2002) where the taller cultivars were found to have greater biomass yields. The lower seedling emergence and survival ratings for ‘High Tide’ may have influences the reduced dry matter yield observed due to smaller plant size and lower tiller density.

Three of the cultivars ‘Carthage’, ‘Kanlow’ and ‘High Tide’ had statistically significant increases in dry matter yield from the first harvest year to the second harvest year (Figure 5). This indicates that overall stand establishment is still increasing and mature stands could produce higher yields than seen in these first two years. To adequately evaluate all cultivars it would be prudent to continue evaluations past the third year from establishment. Results from a study done by Fike et al. (2006) indicate that switchgrass yields begin to remain constant approximately 3 to 5yr after establishment. Obstacles with stand establishment during the first few years can result in lower biomass yields until stand density has improved as seen in an experiment done by Lemus et al. (2002).

For the first harvest year ‘Carthage’ had significantly greater dry matter content than all of the other cultivars. ‘Kanlow’ had significantly higher dry matter content than ‘Alamo’ and ‘High Tide’. For the second harvest year there was no significant differences between dry matter content for any of the cultivars. Data for both the first and second harvest years are reported in (Figure 6). The dry matter content of all cultivars in the second harvest year was significantly lower than their dry matter content in the first harvest year. This was not surprising because the first year the field was harvested in late fall two weeks after a snowstorm. This would have resulted in an increase in moisture content in the plants. In the second year the field was not harvested until winter; due to environmental factors. A later harvest resulted in lower moisture content because of the drier weather conditions and lack of precipitation close to the harvest date as well as the length of time for senescence of the plant tissue.

CONCLUSIONS

The highest yielding cultivar in this trial by the second harvest year was ‘Carthage’. This cultivar along with ‘Kanlow’ and ‘High Tide’ had significant increases in yield between the first and second harvest year. If this trend were to continue one of these cultivars could be a viable option for growers in central New Jersey. The lower yielding cultivar ‘High Tide’ should probably not be grown in these conditions due to its lower yields, even with the significant increase in the second harvest year and decreased stand establishment rate.

There was no correlation between initial seedling emergence and later percent plot cover ratings, indicating that initial seedling emergence is not the best indicator for overall plot performance. As expected heading and anthesis dates indicating plant maturity, were highly correlated.

During the first harvest year plant height was positively correlated to lodging rates, resulting from ratings being taken shortly after an early snowstorm. The second year this correlation was not seen, resulting from ratings being taken after the plots had recovered from an early snow storm. These results indicate that switchgrass plants, regardless of height are able to resist lodging due to snowfall and will return upright if provided a recovery period. This trait is favorable when selecting plants for production, as farmers will be able to harvest the plants later in the season regardless of precipitation events in the early winter.

Not surprisingly plant height was positively correlated to heading and anthesis dates, which indicates that later maturity allows for increased plant growth. Similar results were seen in a study conducted by Cortese and Bonos (2012) where plant height was correlated to heading date ($r2= 0.80$ $p=0.006$) and anthesis date ($r= 0.84$; $p= 0.0121$) (Cortese and Bonos, 2012). Plant height was positively correlated to harvested yield the first harvest year, but was not correlated the second harvest year. Because initial yields were not optimal this data does not indicate a strong correlation between plant height and harvested yield. A third year of data needs to be taken to determine whether there is a correlation after the stands have reached their full potential.

The lower seedling emergence and survival ratings for 'High Tide' could affect the overall dry matter yield resulting from smaller plant size and lower tiller density. From the data present it would appear that 'Carthage' would be the best selection for this area and soil type, however further evaluations should be done to determine the long-term performance of this cultivar as compared to the other closely yielding cultivars. In a study done by Fike et al. (2006) total biomass production did not reach maximum potential until the third harvest year. Therefore, additional years of data collection are necessary to determine the long-term potentials of the 5 cultivars in this area.

Figure 1. Percent seedling emergence; measured with a frequency grid, for 5 switchgrass cultivars grown in Middlesex County, NJ. Data taken 1 month after planting; 13 Aug. 2010. Different letters indicate significant $p < 0.01$ difference between cultivars.

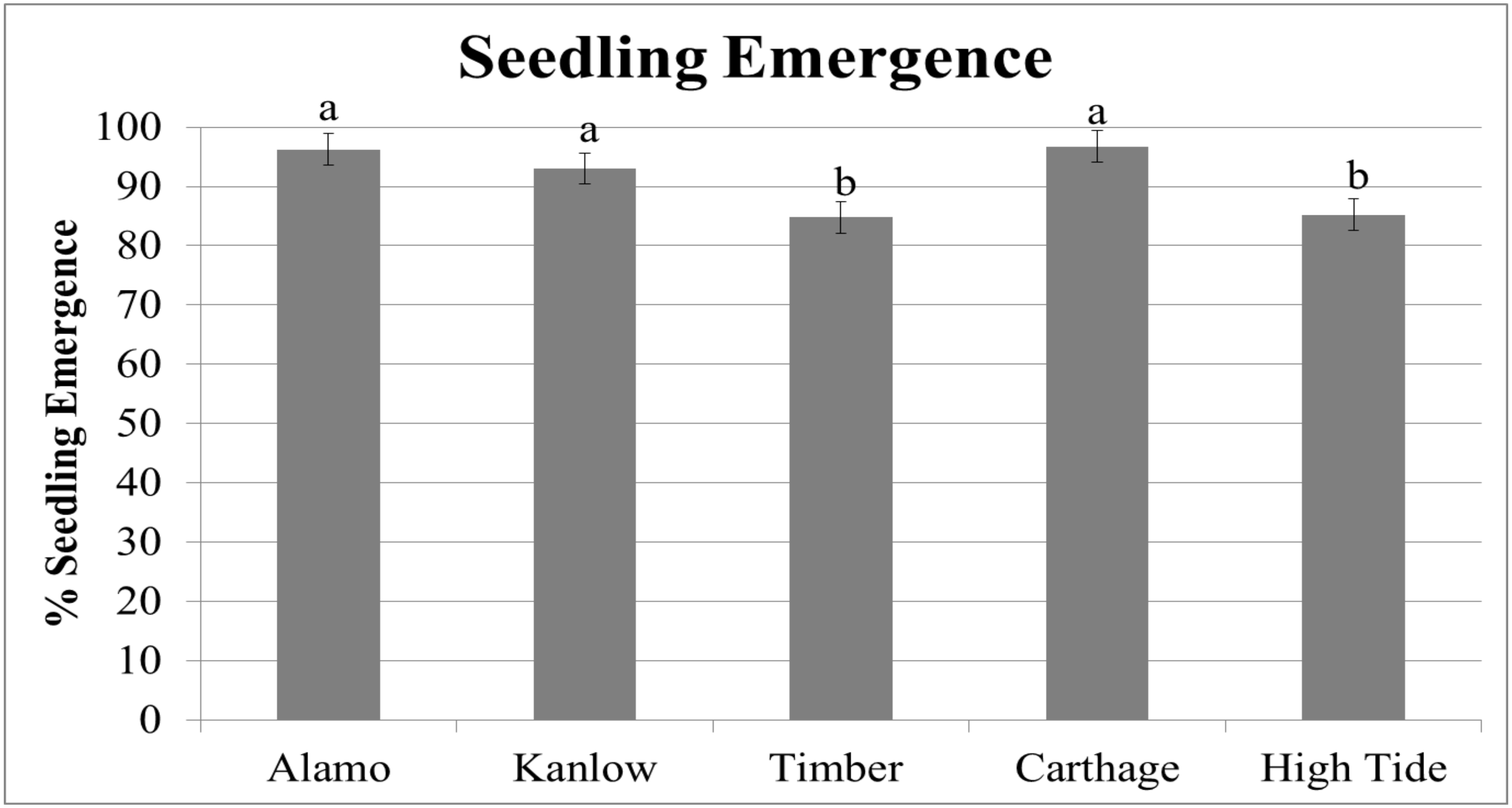


Figure 2. Percent stand survival; measured with a frequency grid, taken in the first spring 22 June 2011. Different letters indicate significant $p < 0.01$ difference between cultivars.

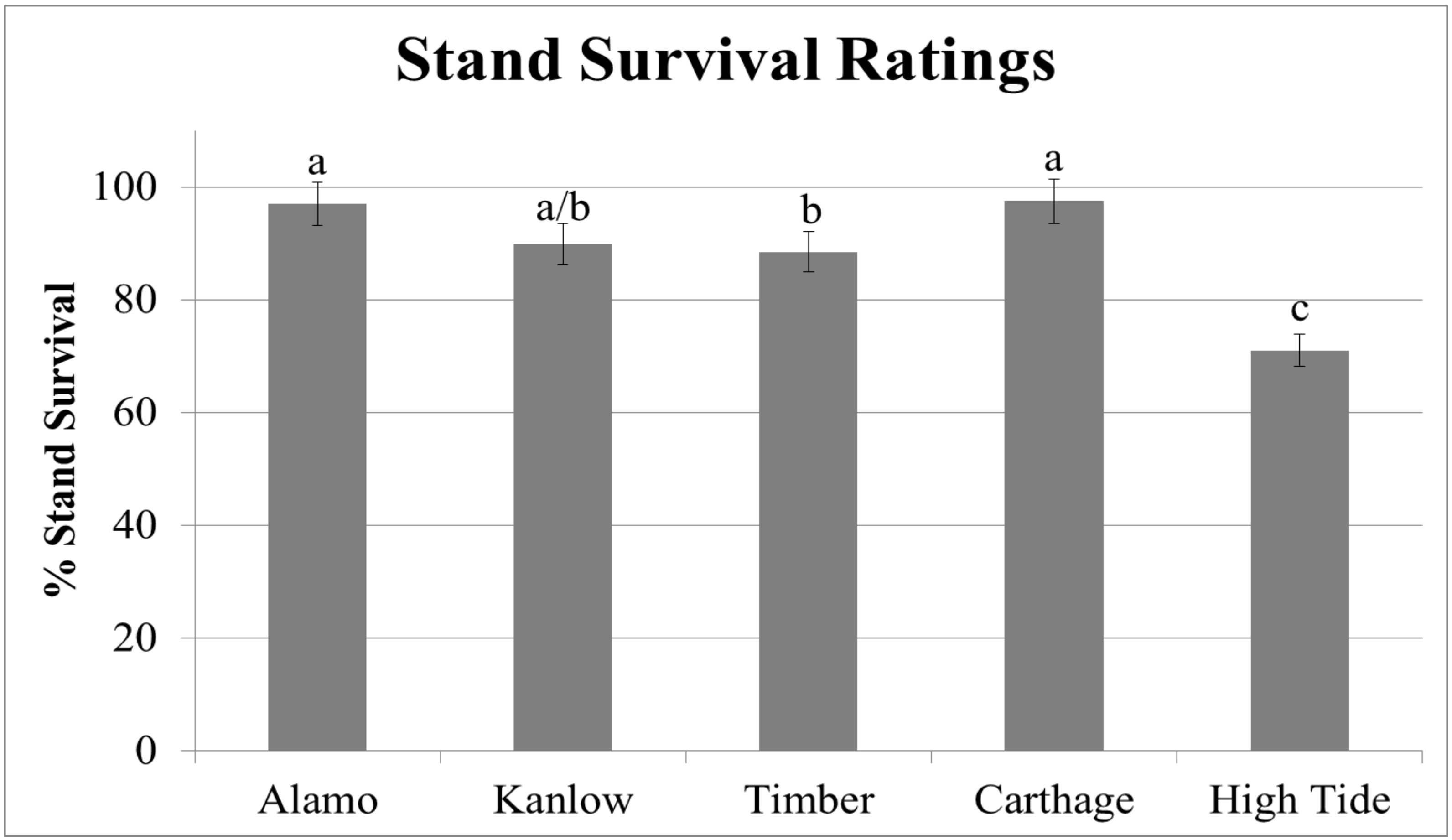


Table 1. Heading (measured by approximately 50% of heads emerged) and Anthesis (pollen present in at least some of heads) dates taken in 2011 and 2012. Different letters indicate significant p< 0.05 difference between cultivar for each year.
*** indicates a significantly p< 0.05 earlier dates for heading or anthesis from year 1 to year 2.**

	Range of Dates			
Cultivar	**Heading 2011**	**Heading 2012**	**Anthesis 2011**	**Anthesis 2012**
Alamo	216 b	213 a*	245 a	237 a*
Kanlow	212 c	211 a*	243 a	233 a*
Timber	223 a	201 b*	242 a/b	227 b*
Carthage	210 d	187 c*	232 c	216 c*
High Tide	211 c/d	200 b*	234 b/c	213 c*

Figure 3. Plant height (determined by average height of panicles) taken 5 Nov. 2011 and 16 Nov. 2012. Different letters indicate significant $p < 0.01$ difference between cultivars for each year. * Indicates a significantly $p < 0.05$ greater average height from year 1 to year 2 within a cultivar.

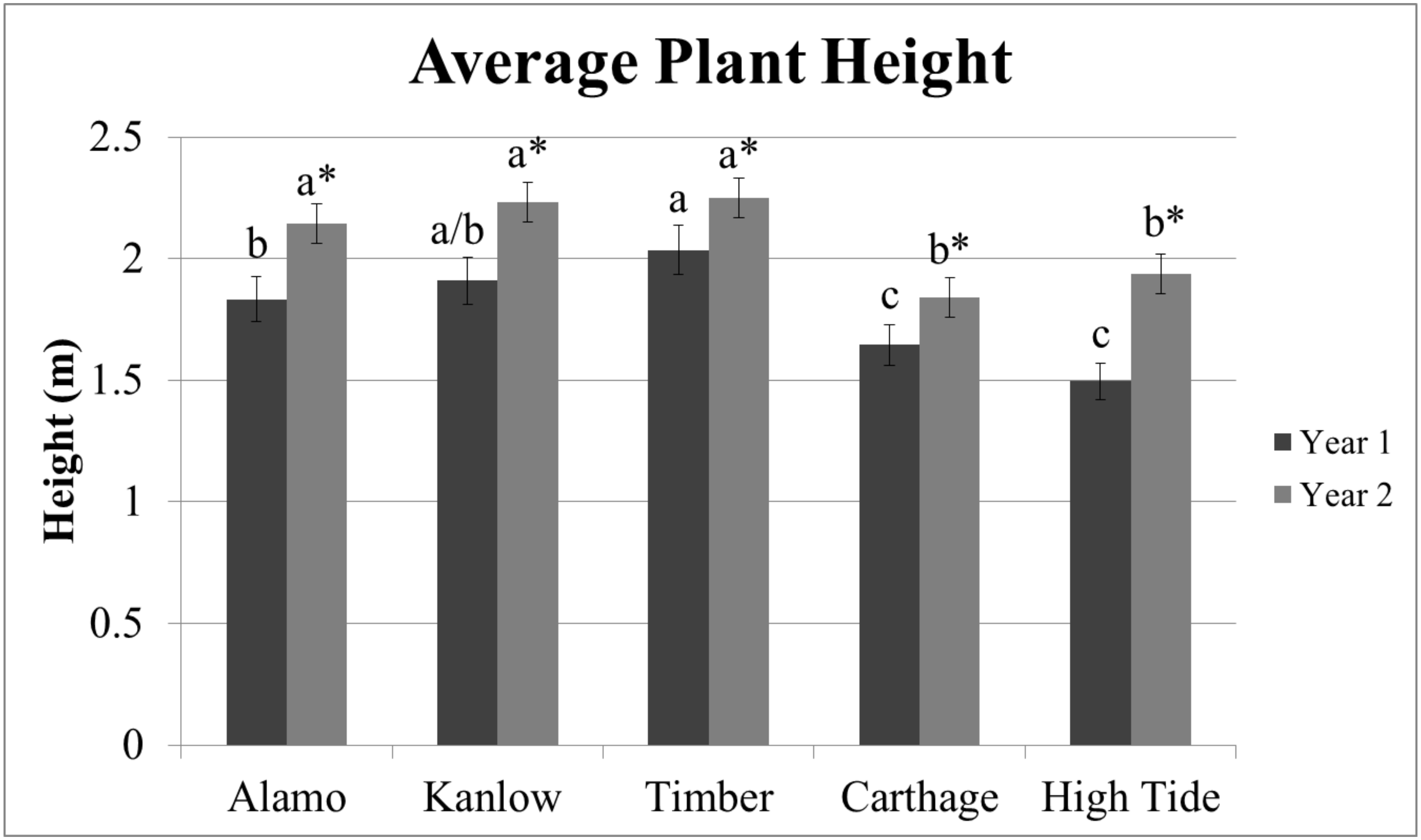


Figure 4. Lodging ratings taken 5 Nov. 2011 and 16 Nov. 2012 for 5 switchgrass cultivars grown in Middlesex County NJ. Different letters indicate significant p< 0.01 difference between cultivars for year one. * indicates significantly p< 0.05 less lodging from year 1 to year 2.

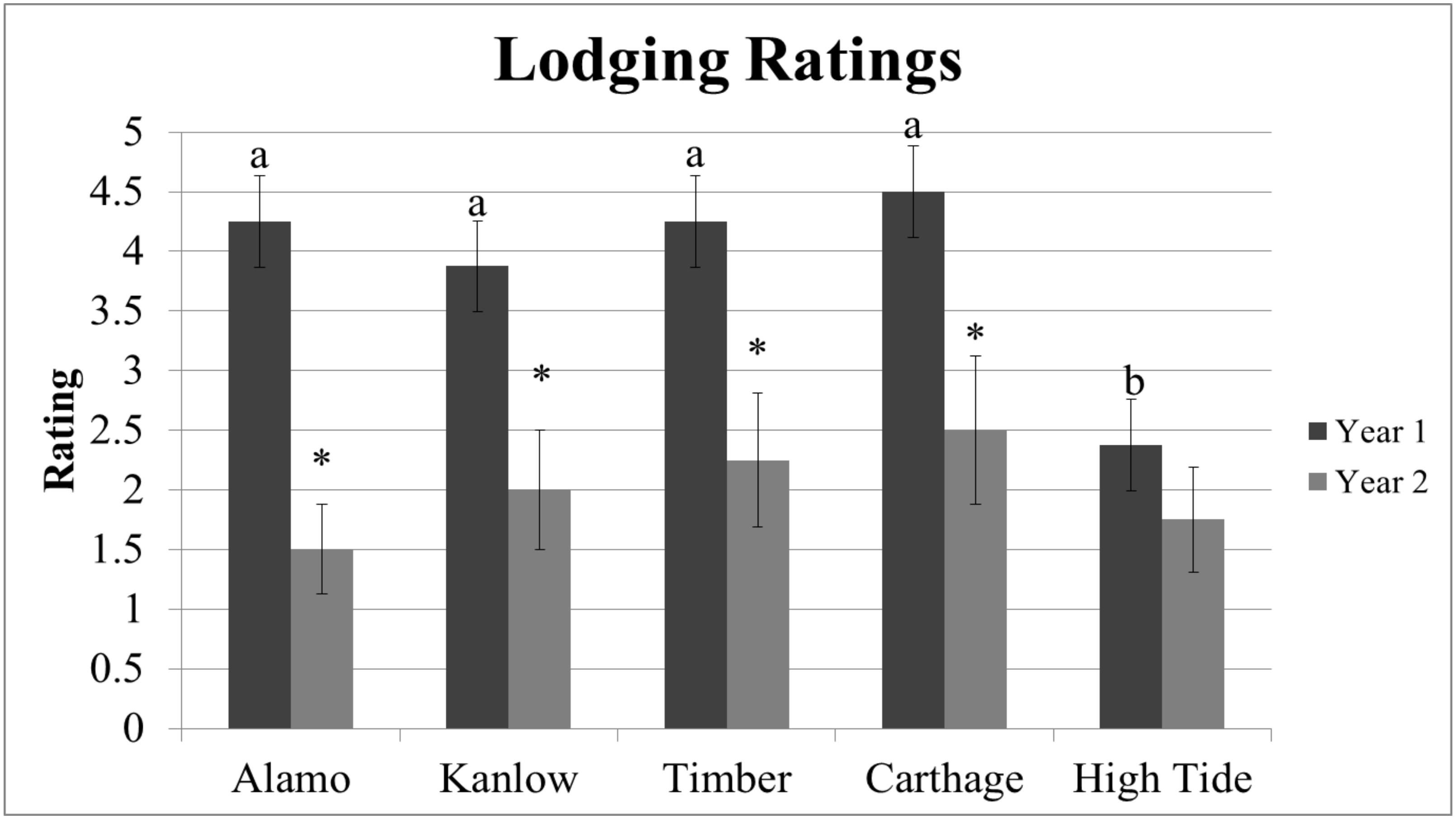


Figure 5. Average dry matter yield in kg ha^{-1} for 5 switchgrass cultivars grown in Middlesex County NJ. No significant difference between cultivars was seen in the first harvest year. Different letters indicate significant $p < 0.05$ differences between cultivars for year 2. * indicates significant $p < 0.05$ increases in average dry matter yields from year 1 to year 2.

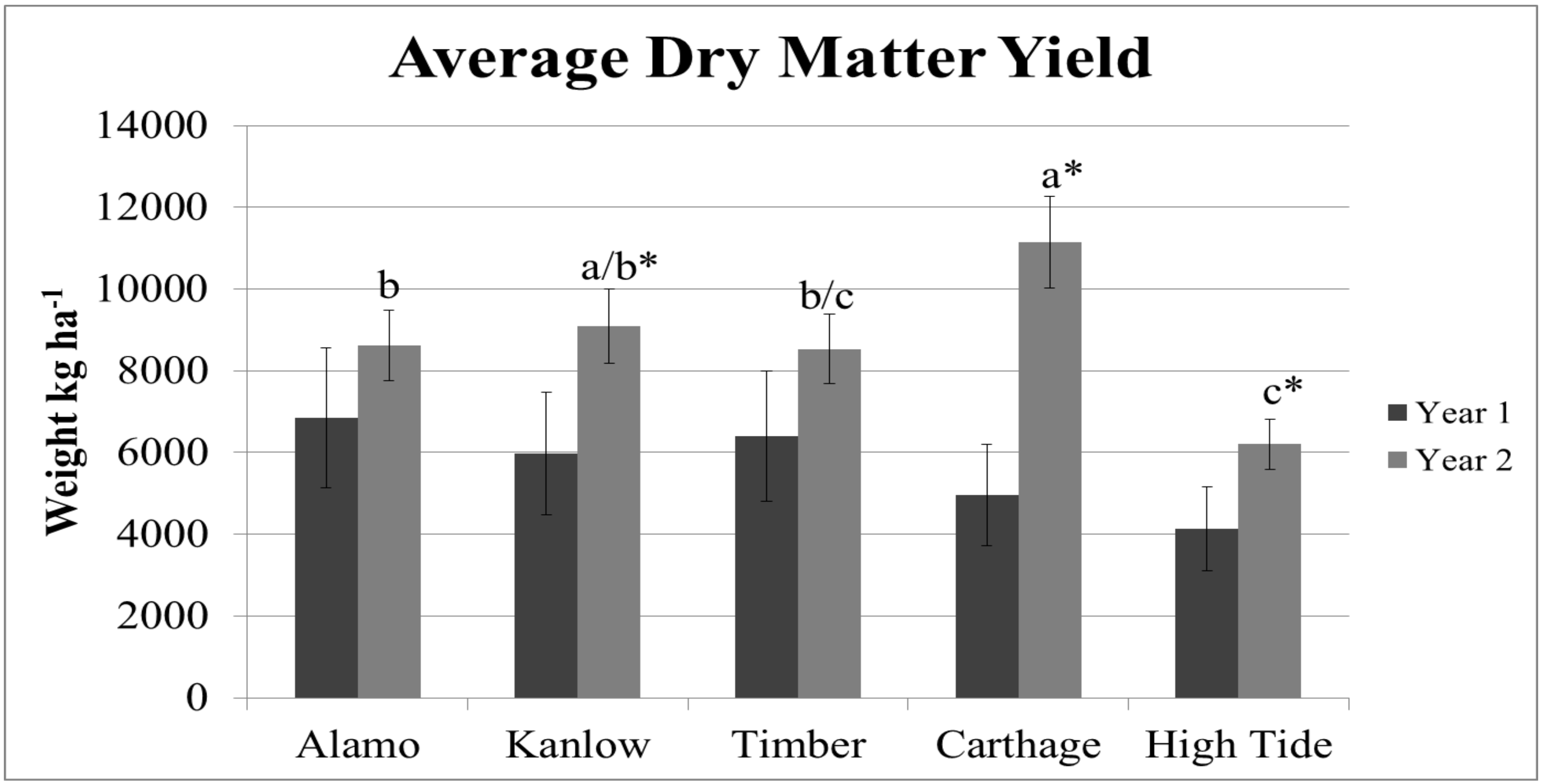
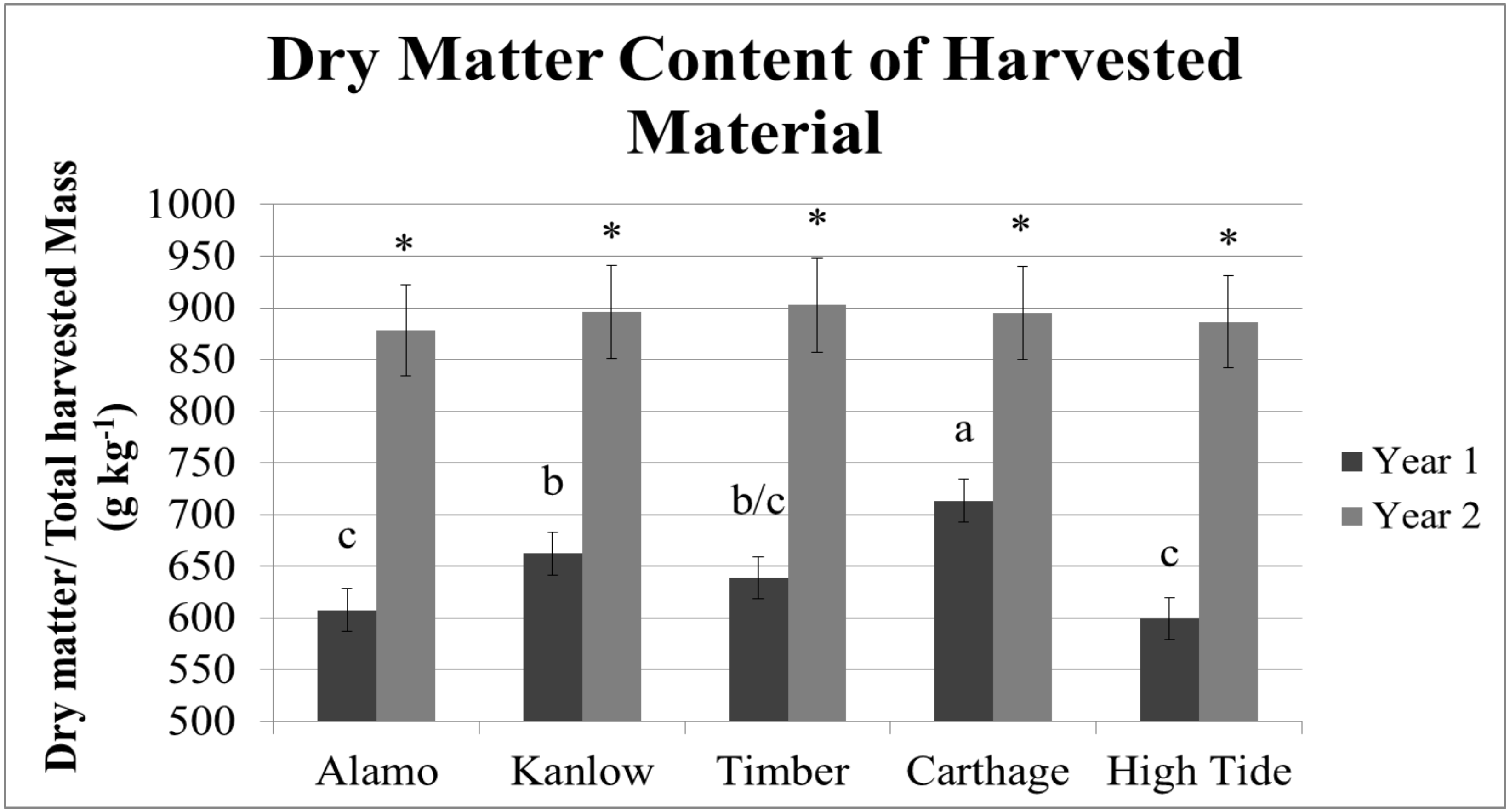


Figure 6. Dry matter content for 5 switchgrass cultivars, grown in Middlesex County, NJ. Different letters indicate a significant difference in dry matter content at $p < 0.01$ between cultivars in the first harvest year. No significant difference between cultivars was seen the second harvest year. * indicates a significant $p < 0.05$ increase in dry matter content from year 1 to year 2.



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Chapter 3: The Effect of Different Compost Amendments on Establishment, Growth Characteristics and Yield of Switchgrass (*Panicum virgatum L.*) in NJ

ABSTRACT

Successful establishment of switchgrass (*Panicum virgatum L.*) for bioenergy can be optimized using nutrient sources that are effective in nutrient delivery. Small- scale switchgrass production on farms in the Northeast would benefit from using low- input methods and using locally available nutrient sources. Four locally available compost materials; horse manure with food waste, horse manure with sawdust, leaf compost and an acai berry compost waste product were either tilled into the soil or applied to the surface of the field at seeding of 'Carthage' switchgrass. The amendments were evaluated for their effect on overall establishment, growth and dry matter yields of switchgrass. The trial was established in July 2010 in North Brunswick, NJ. Seedling emergence ratings were taken 30 days after planting, stand survival and quality ratings, heading and anthesis dates, plant height, lodging, dry matter yield and dry matter content were collected for two years after establishment. Plots amended with acai berry, horse manure plus food waste and horse manure plus sawdust had significantly greater ($p<0.05$) seedling emergence than the plots treated with a synthetic fertilizer. There were no significant differences in dry matter yield among compost type, application method or harvest year. While mixing compost into the soil before planting may improve initial seedling emergence, overall stand establishment and dry matter yields were not affected by the source of this one time nutrient application. To determine the long- term benefits of each

nutrient source annual applications must be applied and stand performance and production evaluated past the establishment years.

INTRODUCTION

Switchgrass (*Panicum virgatum L.*) is a warm season perennial grass native to North America that is adapted to many regions with different environmental, climactic and soil conditions (Casler and Boe, 2003). Because it is perennial, costs associated with the planting and establishment need only be incurred once a decade, since the crop can be harvested for ten years without significant loss in biomass production (Duffy and Nanhou, 2002).

The perennial nature of switchgrass also improves soil conditions because a permanent root system decreases erosion, improves local water quality and is more nitrogen efficient (Lemus et al., 2002; Nabity et al., 2012). Being native to the United States, also provides the added benefit of adaptation to the local environment so widespread crop production should have less of an impact on the local ecosystem than the introduction of a non-native species.

The ability to grow switchgrass on preserved grasslands is important because this allows the production of switchgrass without displacing vital food crops (Vogel, 1996). Preserved grasslands; including Conservation Reserve Program or CRP fields, are maintained to support the local wildlife including local bird populations (Murray et. al., 2003). Harvesting after a killing frost and applying manure compost as a nitrogen source in the spring is the best way to reduce harvest impacts on stand survival the following growing season (Lee et al., 2007).The recommended late winter harvest will not interrupt bird nesting season; unlike row crops and pasture lands (Sanderson et al., 1999a, Murray et al., 2003) Therefore, the proper maintenance of this crop mirrors the recommended maintenance schedule for preserved grasslands.

Farmers prefer crops that require less weed management, which can cut into their profit (Hipple and Duffy, 2002). In many cases preserved grasslands have not been planted or maintained for a number of years and contain a large population of weeds. Annual weeds can prove tough competition for emerging switchgrass seedlings (Rinehart, 2006; Smart and Moser, 1999). Weeds that emerge around the same time as switchgrass compete for space, nutrients and water. Annual weeds are the most competitive because they tend to grow at a faster rate and impede switchgrass establishment and development (Parrish and Fike, 2005). Research has shown that glyphosate applications before planting and the use of a no-till planter can significantly reduce weed competition and increase switchgrass establishment (Parrish and Fike, 2005; Sanderson et al., 2004). Chemical pesticides can be expensive and application requires both equipment and fuel use. In any areas that are also used for wildlife habitats such as CRP fields, the use of chemical applications should be kept to a minimum to reduce their impact on the local ecosystem. Development of alternative weed management techniques can reduce pesticide requirements and any associated costs. A surface application of a compost treatment before or immediately after no-till planting could help to reduce weed growth in the year of establishment, reducing the need for herbicidal applications (Singer et al., 2006). Lee et al. (2007) determined that initial applications of synthetic nitrogen applications increase weed biomass, whereas manure applications increase switchgrass biomass. Applying additional annual compost applications can further reduce weed growth (Lee et al., 2007). The amount of compost material applied was proportional to the increase in stand tiller density (Busby et al., 2006). Application of composts can be a cheap alternative to applying pesticides and reduce excess accumulation of these ‘waste materials’ on farms.

Although considered a low- input crop, switchgrass has been found to respond to nitrogen fertilizer. Studies conducted by Vogel et al. (2002) and Lemus et al. (2008) determined that an annual application of nitrogen fertilizer can increased stand quality. The optimal fertilization period is once annually around May or June of each harvest year (Lemus et al., 2008 and Vogel et al., 2002). Vogel et al. (2002) indicated an annual harvest conducted after the plants had reached full maturity resulted in the greatest biomass yields. Lee et al. (2007) determined that waiting until after the first killing frost increased biomass yield and reduced nutrient loss.

It is realistic to consider that the use of composted materials could replace synthetic nitrogen fertilizers and reduce the cost of crop production. A number of studies have been done to evaluate the effects of organic and waste material applications on the growth and biomass production of switchgrass (Busby et al., 2006; Lee et al., 2007, Sanderson et al., 2001). Composted materials release nutrients at a slower rate than synthetic fertilizers which makes it an appealing option for perennial crops, because they can benefit from a slow- release source that extends nutrient availability and reduces the rate of nutrients leaching from the soil (Butler and Muir, 2006; Helton et al., 2008; Lynch et al., 2004). One study evaluated the effect of compost made up of treated sewage sludge and woodchips on the growth of ‘Kentucky 31’ tall fescue (*Festuca arundinacea*) a cool season grass. In this study, field plots amended with a one-time fertilizer application and compost treatment resulted in higher biomass yields than those that only received a fertilizer application. The compost amendments provided a more long term nitrogen source because the synthetic fertilizer started to leach from the soil before the grass had reached full maturity (Tester, 1989). Research indicates that an initial application of fertilizer and sludge compost followed by annual sludge compost applications significantly increased biomass yields of forage grasses compared to unfertilized control plots (Shiralipour et al., 1992; Warman and Termeer, 2005).

Manure compost has been used in many experiments and provides high levels of nitrogen, in addition to phosphorus and potassium (Butler and Muir, 2006) Application of manure compost increases the organic matter in the soil further improving the soil quality which in turn improves the soil pH, nutrient content, reduces erosion and increases the water holding capacity (Butler and Muir, 2006). A study by Lee et al. (2007) determined that manure applications increased the percent of switchgrass present compared to plots treated with synthetic nitrogen fertilizer. Other studies determined the application of dairy manure compost increased the biomass yield of grass crops including timothy (*Phleum pretense L.*) and Coastal Bermuda grass (*Cynodon dactylon L.*) compared to the unfertilized controls (Lynch et al., 2004, Helton et al., 2008). A quick release synthetic nitrogen fertilizer can be used in addition to an organic amendment to further optimize dry matter yields. (Helton et al., 2008) Application of synthetic phosphorus and potassium resulted in no significant increase in yield (Helton et al., 2008).

Plant waste compost is another readily available nutrient source. Yard waste compost is produced by most homeowners and includes grass clippings, leaves and small branches. Crop residue compost is a ‘waste product’ produced by farms and is composed of undesirable plants and plant parts form the crops they grow. These types of compost are another source of slow-release nitrogen, as well as other macro and micronutrients; which are ideal for perennial crops including switchgrass (Lynch et al., 2004; Singer et al., 2006). In an experiment conducted by Lynch et al. (2004) harvested dry matter yields from high application rates of crop residue compost matched yields from inorganic fertilizer applications over a two year period. Researchers determined that annual application of compost amendments are adequate nutrient sources for high yielding crops including perennial grass forages. Both surface applied and incorporated compost methods increased the overall biomass present in the plots (Singer et al., 2006).

The Acai berry is a fruit that grows native in Brazil and other parts of Central and South America. This is a palm plant that produces dark purple berries. Recently this fruit has become popular in the United States (Mertens-Talcott et al., 2008). Because approximately 90% of the berry is made up of the seed, local companies that produce acai juice products are left with a large amount of 'waste product.' This waste produt has been used as a compost and fertilizer as it contains many nutrients and minerals. Access to large amounts of this compost could be used to fertilize perennial crops and reduce the requirements for synthetic fertilizers. These research results indicate that composted substances could be used to provide crops with at least a portion of the nitrogen they require, which could reduce fertilizer costs.

Synthetic fertilizer is expensive and nutrient requirements can impact grower preferences. Compost amendments could be used to reduce or eliminate synthetic fertilizer requirements. These materials may be less costly than commercial fertilizer. The savings from using these alternative nutrient sources would be maximized if the products could be obtained locally or from the farmers own property.

Although many researchers have evaluated switchgrass in different locations throughout the United States on both fertile and marginal lands, only a few studies have evaluated methods adapted for low maintenance locations in the Northeast and more specifically New Jersey (Bonos et al., 2011). As of 2010 there were approximately 10,300 farms in New Jersey alone, which took up over 296,817 ha of land. Of this area approximately 21,856 ha are designated pasture lands (USDA, 2011). These farmers could benefit from knowledge of the best compost materials to use to minimize weed competition and maximize emergence, stand density and overall yield. The objective of this experiment was to compare the germination rate, stand quality, growth characteristics and dry matter yield of switchgrass using various compost treatments under till versus no-till conditions in Central New Jersey.

MATERIALS AND METHODS

Field preparation, plant material and treatments

The field used for this study was a Woodstown loam with a 0%- 2% slope, a pH of 6.6 and approximately 3.41% organic matter. In July of 2009, the field was mowed to a stubble height of approximately 15 cm and plowed. In August 2009 a glyphosate application was made at the standard rate of 1.12 kg ai ha^{-1}. A cover crop of cereal rye (*Secale cereale*) was planted June 2010.

Seed of ‘Carthage’ an upland cultivar was obtained from the USDA-NRCS Cape May Plant Materials Center. ‘Carthage’, was chosen because it had been grown in the region and was shown to produce adequate yields in New Jersey (Cortese and Bonos, 2012). ‘Carthage’ originated from North Carolina; however, this cultivar had been grown multiple years in New Jersey at the Cape May Plant Materials Center for seed production, so this particular seed source had become adapted to the New Jersey environment (Miller, 2009; Miller, 2006). As per the label the germination percentage of this seed was between 85%- 95%. The seed was planted at a recommended rate of approximately 12.78 kg ha^{-1} of pure live seed (Rinehart, 2006).

Four different compost materials were evaluated in this study. The leaf compost was donated by the County of Middlesex Composting Facility in Middlesex, NJ. The horse manure plus food waste compost was donated by Ag Choice located in Sussex County, NJ. The horse manure plus sawdust compost was donated by Leister Farms in Allentown, PA. The Acai berry waste product was donated by Grefco Minerals Corp. in Bala Cynwyd, PA. The control plots had a synthetic slow release nitrogen fertilizer 24-0-12, which was purchased from Chamberlin and Barclay, Inc. Cranbury, NJ. All materials were applied at the suggested rate of approximately 67.25 kg ha^{-1} nitrogen (Table 1).

Field Design and Maintenance

Compost treatments were applied to the soil on 10 August 2010 at a rate of approximately 67.25 kg ha^{-1} N. In half of the plots the compost treatments remained as a layer on top of the soil. In the other half of each plot the treatments were incorporated into the soil using a Storr Tractor Rototiller model number GT60 (Storr Tractor Co. Somerville, New Jersey). Carthage was seeded into all plots on 12 August 2010 with a Great Plains No- Till Planter model number 1006 (Great Plains Manufacturing Inc. Salina, Kansas) since no- till methods have been used successfully in switchgrass establishment (Rinehart, 2006). Each plot was 5.5 m wide and 45.72 m long for a total plot area of approximately 1 ha. The field was organized in a randomized complete split-block design with the compost amendments as the main plot treatments and till versus no till conditions as the sub-plot treatments. There were four replications per compost treatment.

Plots were irrigated five times during establishment in the month of August 2010 to promote successful establishment. The total amount of water used to irrigate the trial was 37.49 m^3. This equates to approximately 36.8 m^3 ha^{-1}. Weed pressure from annual grassy weeds was high in spring of 2011 so the field was mowed to 0.3 m on 25 May 2011.

2,4-D was sprayed at a rate of 1.11 kg ai ha^{-1} on 3 June 2011 to further inhibit broadleaf weed competition. Borders between each individual plots were maintained throughout the growing season with a standard push lawn mower (Craftsman, Hoffman Estates, Illinois).

In the summer of 2011 there was a heavy infestation of mile- a- minute weed (*Persicaria perfoliata L.*) which was manually removed from the plots. This issue did not recur in 2012.

Data Collection

Plots were evaluated for emerged seedlings in 2010 and stand survival, stand quality, heading date, anthesis date, plant height, lodging, dry matter yield and dry matter content in 2011 and 2012.

Seedling emergence and survival ratings were taken using a frequency grid as outlined by Vogel and Masters (2001). The grid was 0.56m^2 with 25 equally sized cells. The grid was placed within each plot at four random locations and the number of cells; containing at least 1 seedling, were counted. To determine the approximate plant density in a 1 m^2 area, the number of cells out of 100 containing emerged plants, within each plot area were added together and multiplied by 0.4 (Vogel and Masters 2001). Seedling emergence was evaluated on 17 Sept. 2010, approximately 1 month after planting. Survival ratings were taken on 22 June 2011 and on 12 May 2012 using the frequency grid.

Plot quality ratings were taken using a visual rating system to estimate the percent of the plot covered by switchgrass foliage where 1 represented approximately 10% of the plot and 10 represented 100% of the plot. Quality ratings were taken on 1 June, 30 June, 22 August, and 5 November in 2011 and on 22 June and 5 July in 2012. Heading dates were recorded between 28 July to 12 Aug. 2011 and 1 July to 8 July 2012; when panicles first became visible. Anthesis dates were recorded between 2 Aug. to 6 Sept. 2011 and 30 July to 6 Aug. 2012; when pollen was present on 50% of the panicles in the plot.

Plant height was recorded on 5 Nov. 2011 and 16 Nov. 2012. Plant height was measured in three random locations within each plot; an average of these measurements was calculated for each plot.

Lodging ratings were visually rated using a 1-5 scale where 1 represented a plot with 100% completely erect plants, 3 represented a plot with plants angled at 45^{o} to the soil surface and 5 represented a plot with 100% completely lodged plants; lying flat on the soil surface. Ratings were taken on 5 November 2011 and 16 November 2012 after anthesis.

Plots were harvested 11 Nov. 2011 and 7 Dec. 2012. A 0.914 m by 6.1 m sample of each plot was cut with a sickle bar mower (BCS 853, Abbiategrasso, Milano, Italy) leaving a 15 centimeter stubble. The samples were weighed to obtain a total fresh weight. Two subsamples; approximately 500g each, were collected from each sample, weighed and then dried in a forced air drier at approximately 38^{o}C for at least 1 wk. The samples were then weighed again to estimate the dry matter content of the entire harvested sample.

Statistical Analysis

Data was collected over two growing seasons and was analyzed using the Statistical Analysis System SAS 9.2 software for windows. The procedures used to analyze the data included the standard PROC GLM procedure with LSD, which was used to compare ratings from year 1 to year 2 and PROC CORR analyses was used to determine relationships between germination, visual ratings, heading and anthesis dates, plant height and dry matter yield.

RESULTS AND DISCUSSION

Although irrigation improved the overall establishment of the trial, there was a single row of plots on one end of the trial that did not receive an adequate amount of water during germination. The data from these 4 edge plots were excluded from this study and statistical analysis.

Seedling emergence percentages were taken on 17 Sept. 2010, approximately 30 days after planting. Overall, the tilled plots had a higher percentage of seedling emergence than the no-till plots. The tilled plots containing horsemanure plus sawdust, leaf compost and synthetic fertilizer had a significant $p< 0.05$ increase in seedling emergence compared to their no- till counterparts (Figure 1). The increase in seedling emergence in the tilled plots could have resulted from a lower compaction in the soil improving conditions for germination and seedling survival. This data is consistent with data from Monti et al. (2001), which found higher seedling emergence ratings in tilled plots versus plots that were not tilled before seeding. There were no significant differences between the tilled treatments, regardless of compost material used, the percent seedling emergence remained consistent.

Comparing the no-till plots; the horse manure plus food waste, acai berry and horse manure plus sawdust had significantly greater germination than the no-till synthetic fertilizer control plots ($p < 0.05$) (Figure 1). Although the percent emergence was not as high as the tilled plots the added amendments might have increased the amount of moisture present and stored in the soil aiding in switchgrass seed germination. The added cover may have also decreased weed competition increasing seedling survival and emergence. There were no significant differences among the tilled treatments.

In addition the horse manure plus sawdust and leaf compost had higher carbon to nitrogen ratios than the other compost amendment (Table 1); which could have reduced the nitrogen availability in the no-till plots. In addition the tilled plots would have had the additional compost material mixed into the top layer of the soil possibly providing the seeds with additional nutrients as seedling emergence began, supporting the young seedlings early in their development. This was not seen in the plot containing the synthetic fertilizer or plots containing the acai berry material. The plots containing the synthetic fertilizer did not contain a compost amendment so the no-till plots did not have extra organic matter to increase the moisture holding abilities of the soil. The acai berry compost was dustier and lighter than the other composts, so it may not have been as effective in moisture retention.

Percent stand survival taken 22 June 2011 and 12 May 2012 indicated a significantly greater stand density of all plots in 2012 compared to 2011 (Figure 2). This is most likely due to an increase in the stand maturity and increased tillering; which occurs during the first 3 to 5 years of establishment when the plants are subject to favorable conditions (Fike at al., 2006). In addition, in 2011 the tilled plots containing leaf compost and horse manure plus sawdust had significantly greater ($p < 0.05$) stand density than their no-till counterparts (Figure 2). In 2012 only tilled plots containing the leaf compost had significantly greater ($p < 0.01$) stand density than their no-till counterpart (Figure 2). These compost amendments had the highest carbon to nitrogen ratios. Where these amendments were tilled into the soil, these nutrients were most likely mixed and dispersed into the soil reducing the C:N ration in the top of the soil profile and could have increased the soil quality aiding in the switchgrass growth and development.

Visual plot quality ratings taken on 30 June 2011 and 22 June 2012 indicated no significant differences between compost treatment or application method (data not shown). It is possible that plot stands that initially had lower germination ratings were able to catch up to higher germinating plots later in the growing season as a result of an increase in plant vigor or delayed germination. This was seen in a study done by Shaidaee et al. (1969), where a younger seed lot was slower to emerge, but had higher percent emergence by the end of the trial.

The plots in this study were quite large and by the middle of the summer the switchgrass was so tall the middle of the plots could not be evaluated. A study run by Lemus et al. (2002) found that the highest yielding cultivar had large patches within the plot areas with no switchgrass growth. Therefore, visual quality ratings which are taken by standing at the edge of each plot and estimating the total fraction of the area covered by switchgrass foliage may not be the best indicators of total biomass present. These results indicate that emergence ratings do not necessarily correspond with long- term stand quality. In addition there was no difference in stand quality between amendment application. This data is supported by previous research by Rehm (1990) who found that different establishment methods; conventional or no- till, did not affect long- term plot quality or stand establishment.

Although not a specific objective, the overall plot ratings were significantly higher in 2012 average plot rating 7.2 compared to 2011 average plot rating 3.8. It is expected that during the initial establishment years that stand density should increase (Fike, et al., 2006).

In 2011, the heading dates ranged from 206 to 228 d for all cultivars and anthesis dates ranged from 231 to 252 d. In 2012 heading dates ranged from 193 to 190 d and anthesis dates ranged from 212 to 219 d. As expected heading and anthesis dates were highly correlated ($r^2= 0.65$ $p< 0.01$) as both indicate stages of maturity. No significant differences between compost treatment or application method were found. The first harvest year had significantly later heading ($p< 0.01$) and anthesis ($p< 0.01$) dates than the second harvest year; which most likely resulted from unseasonably warm weather that occurred early in the spring of 2012, which could have sped up plant maturation.

Average plant height for each plot was measured before harvest 5 November 2011 and 16 November 2012. No significant differences between compost treatments or method of application were found. Average plant height the second harvest year was significantly taller ($p< 0.01$) than average plant height the first harvest year (data not shown). This was expected as stand quality and plant height does not reach its optimal potential until after the first three to five establishment years.

No significant differences between compost treatment, application method or year of harvest were found for dry matter yields which ranged around 4.67Mg ha^{-1} and 6.53Mg ha^{-1} (data not shown). This data is not consistent with research done by Fike et al. (2006) who found that switchgrass yields continued to increase up to the third year after establishment; however in their trial additional nitrogen applications were applied annually to supplement nutrient requirements after harvesting. It is suggested that a source of nitrogen fertilizer should be applied after each harvest (Lee et al., 2007; Guretzky et al., 2011) however; we were unable to get all compost materials donated for a second year and budget restraints prevented their purchase after the 2011 harvest.

Therefore, limited nitrogen availability could account for the lack of biomass increase from the first to the second year. In addition the compost itself might have caused a nitrogen deficiency, if the carbon to nitrogen ratio was too high there may not be enough nitrogen available to the switchgrass. Obstacles with stand establishment during the first few years can also result in lower biomass yields until stand density has improved as seen in an experiment done by Lemus et al. (2002).

The no-till control plots had significantly lower dry matter content than any other treatment in 2011; while the tilled leaf compost had the highest dry matter content ($p < 0.01$) (Figure 3). In the second harvest year all compost treatments and application methods had significantly lower ($p < 0.01$) moisture content than their first harvest year counterparts (Figure 3), however this was expected because plots were harvested two weeks after a snowstorm the first harvest year. This would have resulted in an increase in moisture content in the plants. In the second year the field was not harvested until winter; due to environmental factors. The later harvest date resulted in lower moisture content due to drier weather conditions and a lack of precipitation before the harvest date; it also allowed a longer period of time for senescence of plant tissue.

CONCLUSIONS

The data from this field trial indicated the importance of evaluating all factors of a switchgrass stand to determine overall stand quality and long- term biomass production. Although there were initial significant differences between compost treatment, application method and emergence ratings these differences were not seen in harvested yield. This indicates that emergence ratings may not be a great indicator of long- term stand quality or biomass production. Additional research determined that seeding rate of pure live seed (pls), an estimate of the seedling emergence percentage, did not correlate with biomass yields (West and Kincer, 2011). Therefore, the initial emergence rates; which generally correlate to the seeding rate of pls, would not necessarily have a direct impact on biomass yields.

Visual stand density ratings in this study were taken by standing at the edge of each plot and estimating the total fraction of the area covered by switchgrass foliage. These ratings determined an overall higher quality in stand establishment the second harvest year; however, harvested dry mass yields did not reflect these observations. This indicates that this rating system may not be the best indicators of total biomass present, as this method can be unreliable in large plots because as the plants grow taller, patches or empty areas toward the middle of the plot, are less likely to be spotted. Stand thinning can also occur resulting in plots with lower plant frequencies; which can support the growth of larger plants. These trends could lower percentages based on frequency grids without affecting plot quality ratings and harvested yields.

Another possibility is that the stands required an additional application of nitrogen. Although stand density improved from the first year to the second, a significant increase in biomass yields may have required additional nutrients. No difference in stand quality was observed between the surface versus tilled applications of the compost. Although the compost treatments provided a slow- release source of nitrogen it was may not have been able to provide an adequate quantity of nitrogen during the second harvest year.

Overall, applications of compost mixed into the soil may be beneficial and improve initial switchgrass stand emergence by providing required nutrients and increase the organic matter present. The application of compost mixed into the soil may provide an advantage to the switchgrass seedlings during the establishment year; however this advantage is not long term as the overall stand quality of all plots after the 2 year period was equivalent.

During the first harvest year mile- a minute weed (Persicaria perfoliata) was hand weeded from the plots to prevent a complete loss of the crop. The plots were also mowed during the spring of the second harvest year this reduced annual weed competition. These events could have had a significant impact on plot quality the second harvest year. This data indicates that switchgrass stands can out- compete annual weed competition when adequate procedures are followed in the establishment years and the stand is given multiple years to become adequately established. Additional compost applications would also be required to supplement the nutrient requirement of the crop after additional harvests.

Further applications of compost would have to be applied after harvests and compared to the application of a synthetic fertilizer to determine if future harvested yields are significantly greater in the plots receiving the compost amendment. In addition the cost of the compost material must be compared to the cost of synthetic fertilizer to determine if the differences in yield are equivalent. Continued data collection of these plots for an additional 4 to 5 years would provide a more accurate estimate of each plot's overall potential.

Table 1. Application rate of each compost material, application rate of Nitrogen, and Carbon to Nitrogen ratio for each compost material.

Compost Material	Total Nitrogen	Amount of Compost Applied	Amount of N applied	C to N ratio
Leaf Compost	1.12%	6,000kg/ha^{-1}	67.20kg/ha^{-1}	15: 1
Horse manure plus food waste	1.90%	3,540kg/ha^{-1}	67.26kg/ha^{-1}	11: 1
Horse manure plus sawdust	1.61%	4,170kg/ha^{-1}	67.30kg/ha^{-1}	17: 1
Acai berry compost	0.53%	12,690kg/ha^{-1}	67.26kg/ha^{-1}	6: 1

Figure 1. Percent seedling emergence of five compost treatments and two application methods for switchgrass grown in Middlesex County, NJ. (Data was taken one month after planting; 17 Sept. 2010. Different letters indicate significant difference at $p < 0.05$ between compost treatments. An * indicates significantly greater germination at $p < 0.05$ in tilled versus no-till plots).

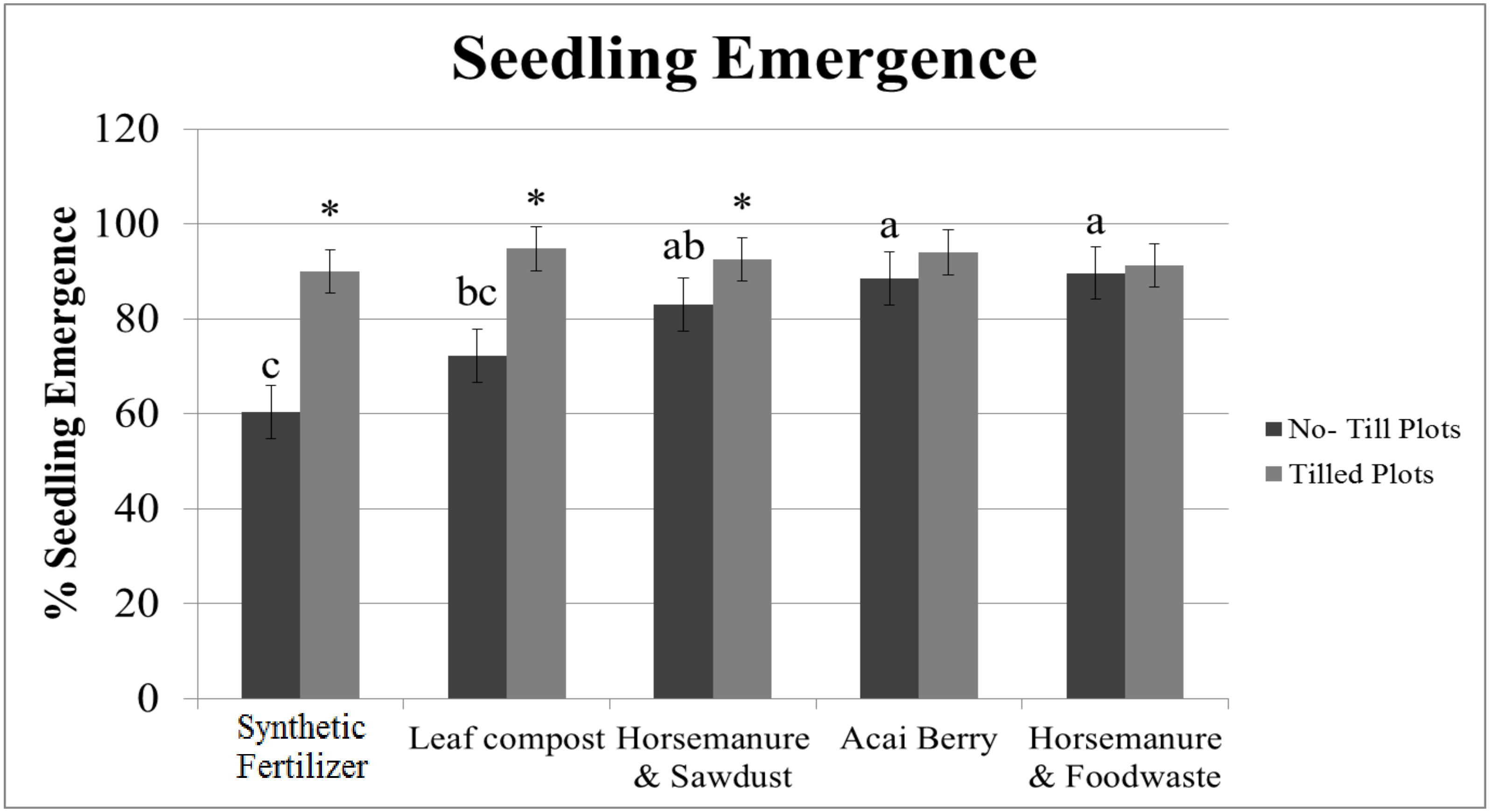


Figure 2. Percent stand survival of five compost treatments and two application methods for switchgrass grown in Middlesex County, NJ. (Different letters indicate significant difference within that specific year and category. * indicates significantly higher percent survival in tilled plots compared to their no-till counterparts within that year).

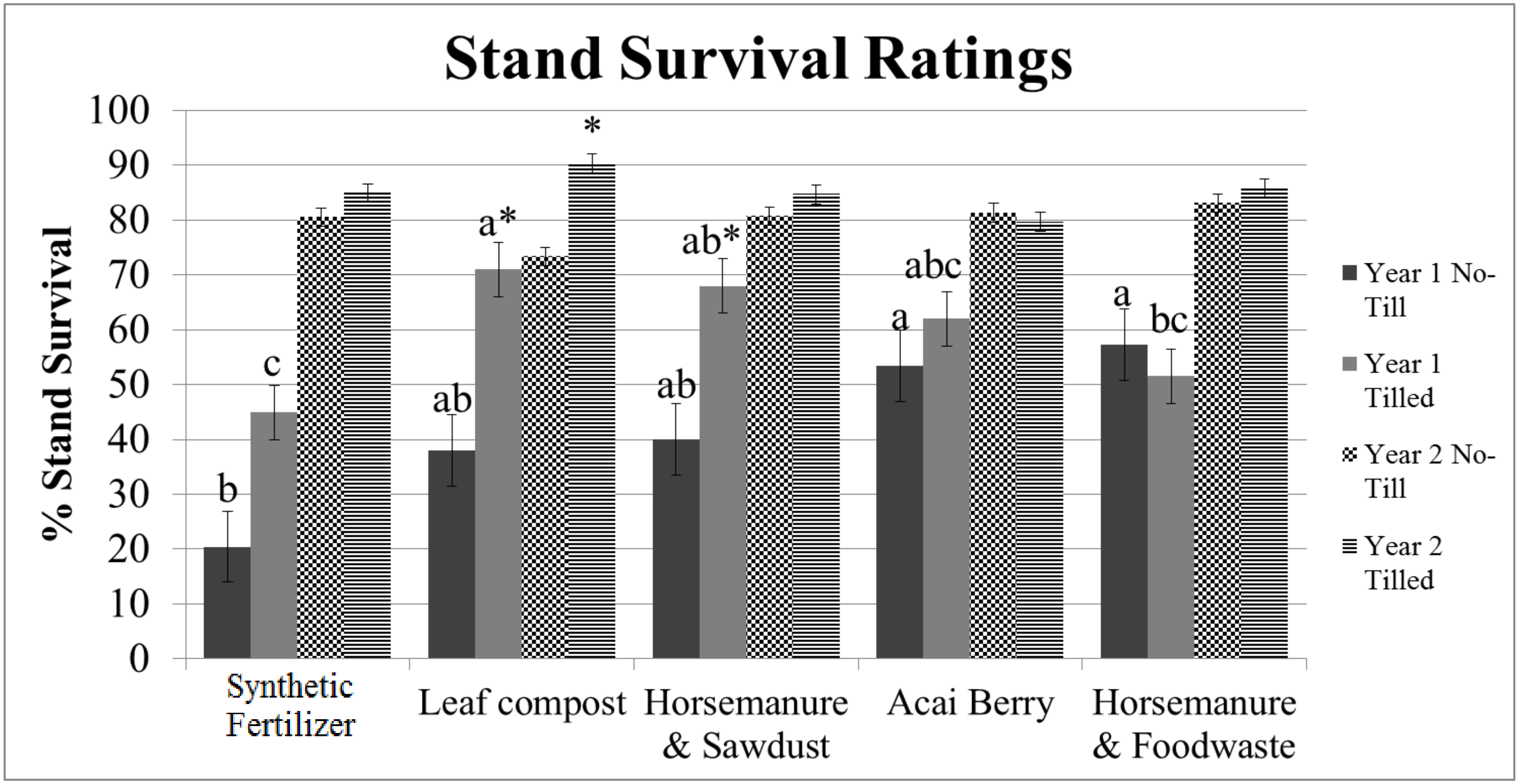
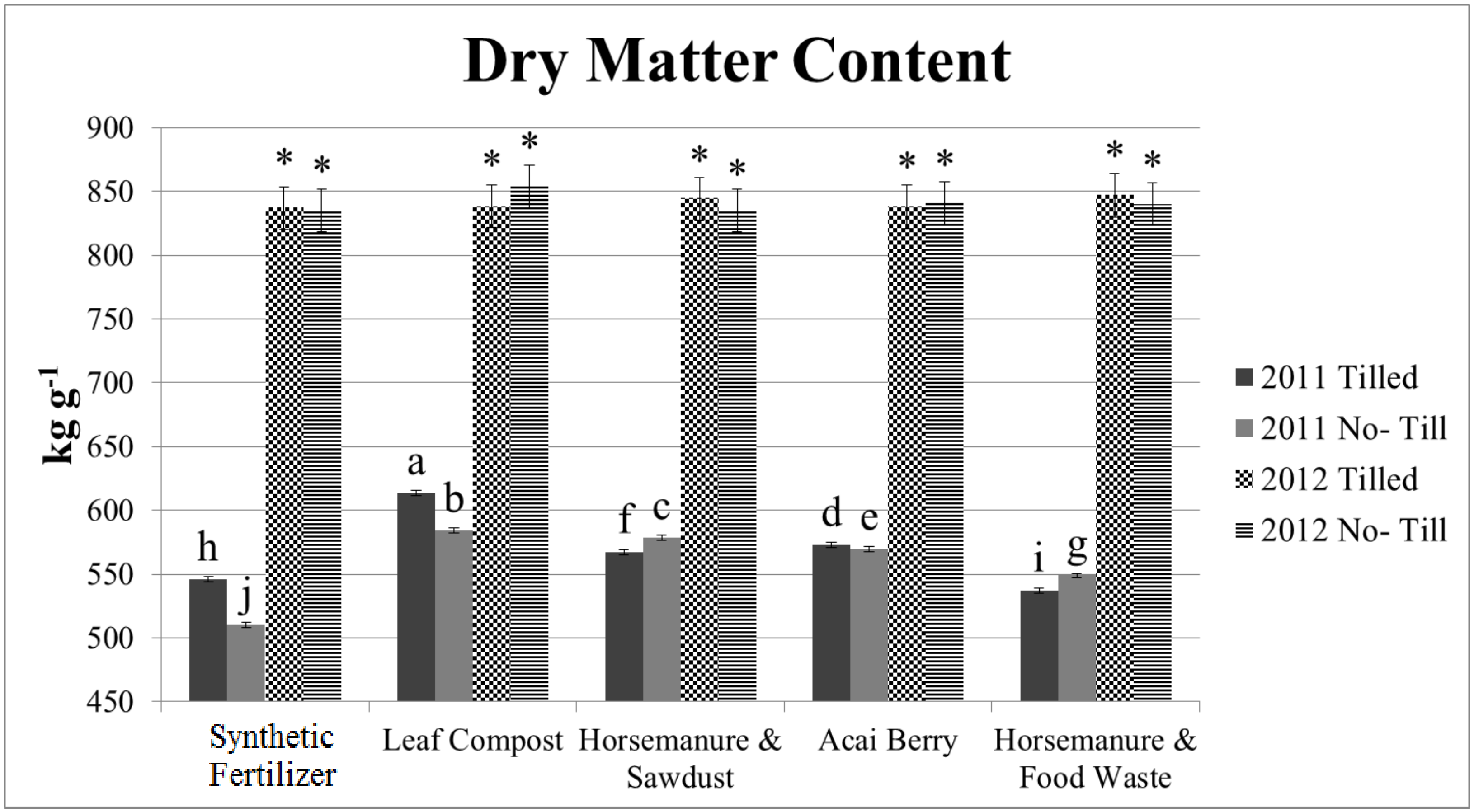


Figure 3. Dry matter content of five compost treatments and two application methods for switchgrass grown in Middlesex County, NJ. (Different letters indicate a significant p< 0. 01 difference in dry matter content between compost treatments and application methods in the first harvest year. * indicates a significant p< 0.01 difference in dry content from year one to year two).



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Chapter 4: Germination rates of Switchgrass (*Panicum virgatum L.*) Cultivars of Different Seed Ages at Various Temperatures in a Growth Chamber

ABSTRACT

The use of switchgrass (*Panicum virgatum L.*) as a bioenergy crop would be optimized by uniform germination. Many factors affect switchgrass germination rate, including seed age, cultivar and soil temperature. This trial compared the germination rate and percentage of five different seed lots; Carthage seed from 2007 and 2011 and Timber seed from 2009, 2010 and 2011, under three different temperature regimes in a growth chamber. Temperature settings were based on the average monthly temperature in North Brunswick, NJ. All trials were run at 14hrs light/ 10hrs dark, 75% relative humidity and 350µE light intensity. A standard germination trial was set for alternating temperatures of 25^{o}C (light) and 15^{o}C (dark) settings, May trials were set for 22^{o}C (light) and 10^{o}C (dark), June trials were set for 27^{o}C (light) and 14^{o}C (dark), July trials were set for 29^{o}C (light) and 18^{o}C (dark). The total number of germinated seedlings was counted and recorded after 6, 12, 18 and 24 days where germination was determined to have occurred after both the first leaves and a 2mm portion of roots had developed. Carthage 2011 had significantly ($p < 0.01$) greater germination rate than all Timber seed lots for the June and July temperature settings. Carthage 2007 had significantly ($p < 0.01$) greater germination rate than all Timber seed lots for the July temperature settings. Timber 2011 had significantly ($p < 0.01$) lower germination rates than all other seed lots for all temperature settings. The temperature settings did not have a significant effect on cumulative germination of any seed lot. These results indicate that increased temperature

can significantly increase the germination rate of switchgrass seed, but not the overall percent of germinated seedlings. In this study the quality of the seed lot as determined by visual estimation of seed size had a significant ($p < 0.01$) impact on germination rate. The age of the seed lots did not have a significant impact on the germination rate.

INTRODUCTION

Switchgrass (*Panicum Virgatum L.*) is a warm season perennial grass native to North America and is adapted to many climates and environmental conditions (Casler and Boe, 2003). Switchgrass was chosen for this study because it is a perennial crop and can be harvested for ten years without significant loss of production. Therefore, field preparation, planting and establishment costs are only incurred once every ten years (Duffy and Nanhou, 2002). For these reasons researchers have become interested in evaluating this grass as a bioenergy crop. Breeding strategies for successful bioenergy crops also focus on uniform germination and growth, to obtain an adequate return on investment (Wullshleger et al., 2010). However, both forage and biomass crops require adequate stand establishment, persistently high yields, disease resistance and stress tolerance.

Currently switchgrass seeds do not have uniform germination. This trait is beneficial to the plant in its native environment; especially when conditions are unfavorable for seedling growth. A staggered germination rate increases the chance of some seedling survival because not all seeds will germinate when these unfavorable conditions are present. Some of the seeds will germinate later when conditions may be more conducive to survival. For large scale crop production; however, uniform germination is vital. Since dormancy can be the result of a number of factors, finding an effective seed treatment and achieving uniform germination can be difficult.

Uniform germination and subsequent establishment is critical for profitable switchgrass yields. Weeds can prove tough competition for emerging switchgrass seedlings (Rinehart, 2006; Smart and Moser, 1999). Weeds that tend to emerge around the same time as switchgrass compete for space, nutrients and water. Annual weeds are the most competitive because they tend to grow at a faster rate and impede both switchgrass development and establishment (Parrish and Fike, 2005).

One of the most common seed treatments to increase germination is seed chilling, which exposes the seed to a lower temperature for a set period of time, generally the seed is stored at 4^{o}C for approximately 14 days (Beckman et al., 1993). This process was developed to mirror conditions in the natural environment (Adkins et al., 2002). In nature, the seeds are released from the plant in the fall and remain dormant throughout the winter before germinating in the spring. Cold treatments have had the greatest effect on increasing germination and emergence rates when compared to other treatments including wet treatments (Beckman et al., 1993; Hsu et al., 1985 (1)). Another seed treatment, which can be done concurrently with seed chilling is ripening, which requires the seeds be held in storage for a year or more before planting (Parrish and Fike, 2005). Another treatment that can be done involves soaking the seeds in gibberellic acid; this has been shown to cause the seed to release proteolytic and hydrolytic enzymes which provide the seed with nutrients and cause the seed to break dormancy (Adkins et al., 2002).

A physical treatment involves the removal of the seed coat through acid or mechanical scarification, which has also been shown to reduce dormancy (EPA, 2010; Jensen and Boe, 1991; Parrish and Fike, 2005). Specifically mechanical scarification partially removes the seed coat allowing for an increase in water uptake and gas exchange within the seed. This process has been found to increase germination up to 39% in some switchgrass varieties (Jensen and Boe, 1991). Acid scarification has been done using different chemicals. In one experiment researchers soaked seeds in H_2SO_4 for approximately 5 minutes and then rinsed the seeds for another 5 minutes; which increased the overall germination rate (Haynes et al., 1997). Pre-chilling seeds in a KNO_3 solution for approximately 2 days before planting is another method that has been shown to increase germination (Haynes et al., 1997).

Stratification is another technique used and involves placing the seeds in a cool, moistening environment for a number of days before being planted. This process can increase germination; however, the seeds must remain moist until planted. Drying and remoistening the seeds can cause re-dormancy to occur and reduce germination rates by 50% compared to stratified seed that has not been re-dried (Shen et al., 2001). Unfortunately, these treatments require more costly seed preparation and the use of more equipment; which is not necessarily available to small farm operations.

Soil temperature at time of planting is another variable affecting seed germination. It was found by Hsu et al. (1985a) that a cooler soil temperature at the time of planting caused a delay in germination and seedling growth. Planting switchgrass seeds late in the spring, when soil temperatures are higher, can improve germination rates resulting from dormancy; however, this also provides greater competition with native weeds in the field and could reduce survival rates of the stand the following year (Rinehart, 2006; Smart and Moser, 1999). The optimal temperature for switchgrass seed germination is between 25^{o}C and 35^{o}C (Parrish and Fike, 2005). Soil temperatures 20^{o}C and lower can significantly reduce switchgrass seed germination and growth rates (Hsu et. al., 1985a). In Middlesex County, New Jersey the average temperature for the month of May is 22^{o}C during the day and 10^{o}C at night; for the month of June it is 27^{o}C during the day and 14^{o}C at night; for the month of July it is 29^{o}C during the day and 18^{o}C at night.

The objective of this experiment was to compare the germination rate of switchgrass seed of varying ages at the different temperature settings representing the months of May, June and July in Middlesex County, New Jersey.

MATERIALS AND METHODS

Growth Chamber Settings

The average high and low temperatures for three different months; May, June and July, in North Brunswick, NJ were compared to the settings of a standard germination test (International Seed Testing Association, 1985). The growth chamber settings were kept at 14 hours of light and 10 hours of dark with a 75% relative humidity and 350µE throughout the duration of the experiment. The standard germination trial was set for alternating temperatures of 25^{o}C (light) and 15^{o}C (dark) settings. The May trial was set for alternating temperatures of 22^{o}C (light) and 10^{o}C (dark). The June trial was set for alternating temperatures of 27^{o}C (light) and 14^{o}C (dark). The July trial was set for alternating temperatures of 29^{o}C (light) and 18^{o}C (dark).

Plant Material

One upland cultivar, ‘Carthage’, and one lowland cultivar, ‘Timber’, were evaluated in this study. These cultivars were chosen since they had been grown in the region and were shown to produce adequate yields in New Jersey (Cortese and Bonos, 2012). Timber was one of the top performers in an experiment conducted in New Jersey in 2006 (Miller, 2009). All seed lots were obtained from the USDA- NRCS Cape May Plant Materials Center. These varieties were chosen because they tend to perform better in the northeast and produce higher yields than cultivars originating from the Midwest (Cortese and Bonos, 2012; Miller, 2006).

All of the seed was produced at the Cape May Plant Materials Center; however, as a result of environmental conditions in the past seven years not all cultivars produced viable seed each harvest year. The Timber seed lots obtained were from 2009, 2010 and 2011; the Carthage seed lots obtained were from 2007 and 2011. The older seed had been stored in a storage building where temperature fluctuated throughout the year. All of the seed was kept in cold storage at 4^{o}C and 80% relative humidity for a minimum of three weeks before the trials began.

Experimental Design

There were a total of five seed lots and five replicates of each seed lot. Each replicate consisted of a petri dish containing a germination pad with room for 100 seeds. The germination pads were moistened with deionized water and then 100 evenly spaced seeds were placed in each dish. The germination pads were monitored daily and kept adequately moist with deionized water throughout the duration of the experiment.

The petri dishes were randomly arranged in the growth chamber. The dishes were re-randomized every 4 days for the duration of the trial to reduce the effect of placement on the germination rates of each replicate. Each experiment was run twice for a total of two trials per temperature setting.

Data Collection

Two standard germination trials were run at 25^{o}C/ 15^{o}C 14hrs light/ 10hrs dark at 75% relative humidity and 350µE light intensity. Two trials were run for each additional growth chamber setting representing the average temperatures for May, June and July in Middlesex County NJ. Each trial was conducted for a total of 24 days with data collection occurring every six days. Cumulative germination counts were made after 6, 12, 18 and 24 days. Increments of six days were chosen because an experiment performed by Sarath et al. (2006) found 60- 70% germination was achieved by the sixth day in controlled growth chamber settings with the seeds in petri dishes. After the number of germinated seedlings in each dish were counted those seedlings were removed from the dish. Germination was determined to have occurred after both the first leaves and at least a 2mm portion of roots had developed. A Germination Rate Index (GRI) for each seed lot at each temperature setting was calculated using the equation: GRI= (G_1/6)+ (G_2/12)+ (G_3/18)+ (G_4/24) where G_1, G_2, G_3 andG_4 are seedling counts on days 6, 12, 18 and 24 respectively; as described by Hsu et. al. (1985).

Data was analyzed using ANOVA and Correlation procedures with the Statistical Analysis System SAS 9.2 software for windows.

RESULTS AND DISCUSSION

Germination rate index

At the standard growth chamber settings Carthage 2007 seed lot had a significantly greater ($p< 0.001$) germination rate than Carthage 2011 and Timber 2011.

Timber 2009, Timber 2010 and Carthage 2011 also had significantly greater ($p < 0.001$) germination rates than Timber 2011 (Figure 1). At the May temperature settings, Carthage 2007 had a significantly greater ($p < 0.001$) germination rate than any of the Timber seed lots. Timber 2009, 2010 and Carthage 2011 had significantly greater ($p < 0.001$) germination rates than Timber 2011 (Figure 1). At the June temperature settings Carthage 2011 had a significantly greater ($p < 0.001$) germination rate than all other seed lots. While Carthage 2007, Timber 2009 and Timber 2010 had significantly greater ($p < 0.001$) germination rates than Timber 2011 (Figure 1). At the July temperature settings Carthage 2007 and 2011 had significantly greater $p < 0.001$ germination rates than any of the Timber seed lots. Timber 2009 and 2010 had significantly greater ($p < 0.001$) germination rates than Timber 2011 (Figure 1).

All seed lots had the highest germination rate at the July temperature setting (Figure 1). The Carthage 2007 seed lot had a significantly greater ($p < 0.001$) germination rate at the July temperature settings compared to all other temperature settings; it had a significantly greater ($p < 0.001$) germination rate at the June temperature settings compared to the May temperature settings. The Carthage 2011 seed lot had a significantly greater ($p < 0.001$) germination rate at June and July settings compared to the standard and the May settings. These results indicate that Carthage tends to have quicker germination at higher temperatures. The Timber 2009 seed lot had significantly greater ($p < 0.001$) germination rate at the July settings compared to the standard and May settings. The germination rate in June was higher than in May (Figure 1). The Timber 2010 seed lot had a significantly greater ($p < 0.001$) germination rate at the July settings compared to all other settings; it had a significantly greater ($p < 0.001$) germination rate at

June and standard settings compared to May settings (Figure 1). The Timber 2011 seed lot had a significantly greater ($p< 0.001$) germination rate at the July settings compared to the standard and May temperature settings. These results indicate that switchgrass seed of upland and lowland ecotypes germinate better under higher temperatures during the months of June and July. This would indicate that recommended planting dates should correlate with New Jersey's warmest months. This would provide growers with the highest uniformity and percent germination.

At the higher temperature settings, June and July, the Carthage 2011 seed lot had a significantly $p< 0.01$ quicker rate of germination than all of the Timber seed lots. At the lower temperature setting, May, the Carthage 2007 seed lot had a significantly $p< 0.01$ quicker rate of germination than all of the Timber seed lots. In addition all seed lots had significantly $p< 0.01$ quicker germination rates at the higher temperature settings compared to their germination rates at the lower temperature settings.

Total percent germination

At the standard growth chamber settings the Carthage lot from 2007 had a significantly greater ($p< 0.001$) total germination percentage than all other cultivars (Figure 2). The Carthage 2007 seed lot was older than all of the other seed lots, so it may have had a reduced number of dormant seeds. Carthage 2011, Timber 2009 and Timber 2010 seed lots had significantly greater total percent germination than Timber 2011, which by visual estimate had the smallest seeds; this could have impacted the overall viability of the seed. These results are consistent with data found by Smart and Moser (1999) who found that seed size was directly correlated with seedling vigor. At the May temperature settings, Carthage 2007 and 2011 had significantly greater ($p< 0.001$)

percent germination than all Timber seed lots (Figure 2). These particular Carthage seeds could be healthier than the Timber seed lots, or the Carthage plants that produced these seeds could have been better adapted to New Jersey than the Timber plants. Timber 2009 and 2010 had significantly greater ($p < 0.001$) cumulative germination than Timber 2011. Similar results were also seen for June and July temperature settings (data not shown). The Carthage 2007, Carthage 2011, Timber 2009 and Timber 2011 seed lots were not statistically different between temperature settings for total percent germination. Timber 2010 had significantly greater ($p < 0.01$) cumulative germination at the June and July temperature settings compared to the May temperature settings (Figure 2).

At the standard temperature settings Carthage 2007 had greater germination than Carthage 2011. For all temperature settings Timber 2009 and 2010 had greater germination than Timber 2011. These results correlate to a study done by Shaidee et al. (1969) who found that switchgrass seed from older seed lots were found to have higher germination percentages. The seed from the Timber 2011 seed lot was, by visual estimates, smaller than the seed from any other seed lot it also had a significantly $p < 0.05$ lower germination rate and overall cumulative germination. This data is supported by research done by Aiken and Springer (1995) who found a positive non- linear relationship between seed size and germination percentage for switchgrass seed (Figure 2).

For most seed lots, total germination was not significantly different among the temperature settings evaluated. Only Timber 2010 had significantly greater cumulative germination at the higher, June and July, temperature settings (later planting dates). This indicates that planting date does not necessarily affect overall germination rate. However, all seed lots had significantly greater germination rates at the higher temperature settings. This indicates that while temperature does not necessarily influence overall germination it does influence rate of germination. This is important when considering other environmental factors that could affect germination and overall plant/ crop survival.

CONCLUSIONS

the seeds tended to have greater germination at higher temperatures there could be a possible advantage to planting this crop later in the planting season. To prepare a field for planting many farmers use herbicides to reduce weed competition. If the crop plant is able to germinate quickly and uniformly it will be able to take advantage of this period where there is limited weed growth. In this study Carthage 2011 had the quickest germination rate at the highest temperature setting indicating this seed lot would probably perform the best under that farming system.

The Carthage 2007 and 2011 seed lots had significantly greater $p < 0.01$ total germination than the Timber seed lots at the May, June and July temperature settings. The Timber 2011 seed lot had significantly lower $p < 0.01$ total germination than all other seed lots; this seed lot also had the smallest seed as noted through visual observation. This indicates that seed lot quality might be a more significant factor than seed lot age when estimating total germination.

Only Timber 2010 had significantly lower $p < 0.01$ total germination at the lowest temperature setting, May. All other seed lots had comparable germination at temperature settings for May, June and July. This indicates that the change in temperature does not have a significant impact on the overall germination of a seed lot; however it does affect how quickly the seeds will germinate.

Further research must be done to determine if the increase in germination rate is enough to compensate for the later planting date. That is, if planted late when it is warmer, will the switchgrass have enough time to become established before the first frost? The plants must mature quickly enough to survive the winter in order for a later planting date to be a viable option. This would have to be done in a field trial as it would be very difficult to simulate these conditions in a growth chamber.

Figure 1. Germination rate of five switchgrass seed lots evaluated in a growth chamber under various temperature regimes. Germination rate was calculated using the equation in Hsu et al., 1985. Different lowercase letters indicate significant difference at p< 0.01 between months within each cultivar. Different uppercase letters indicate significant differences at p< 0.01 between cultivars for each month.

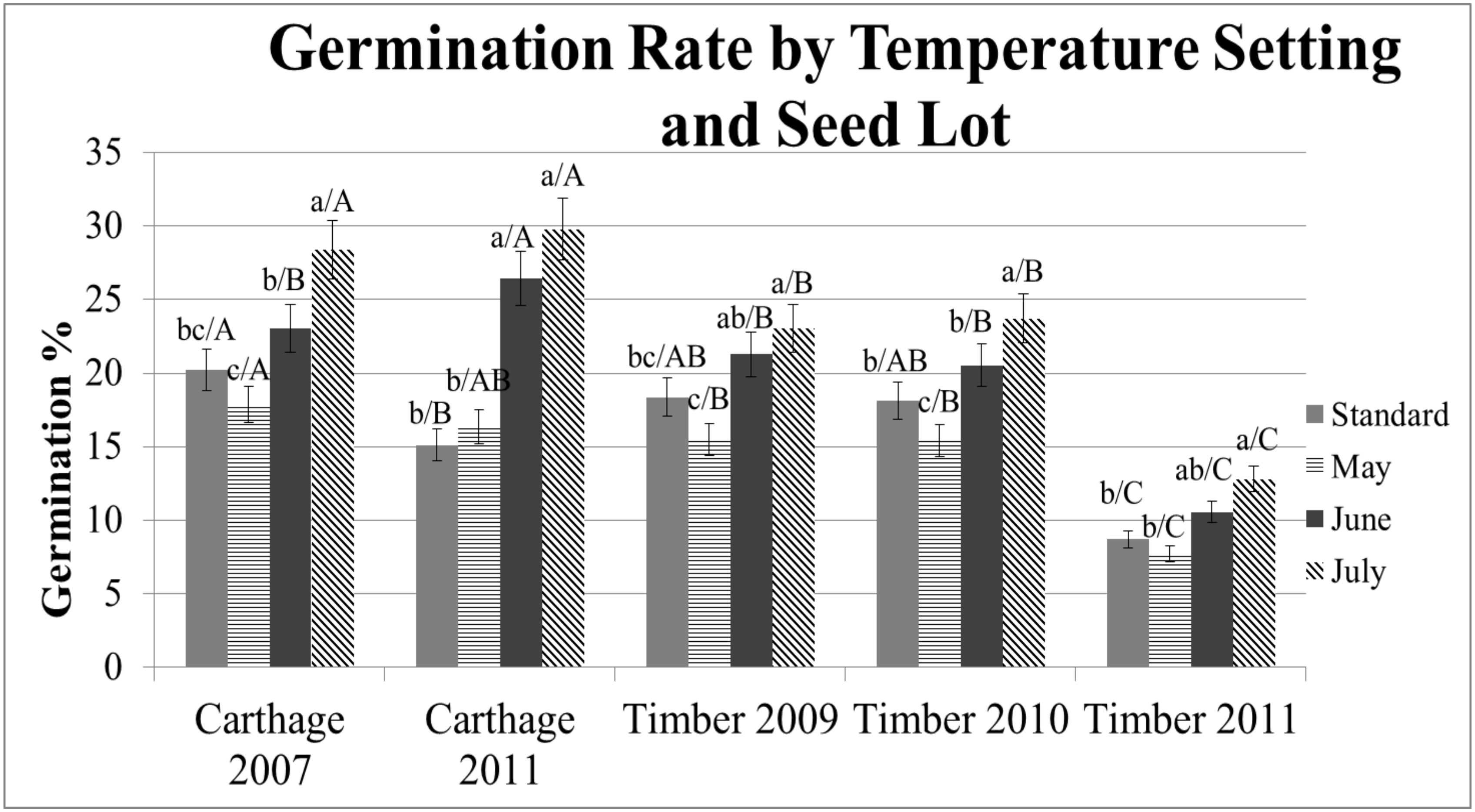
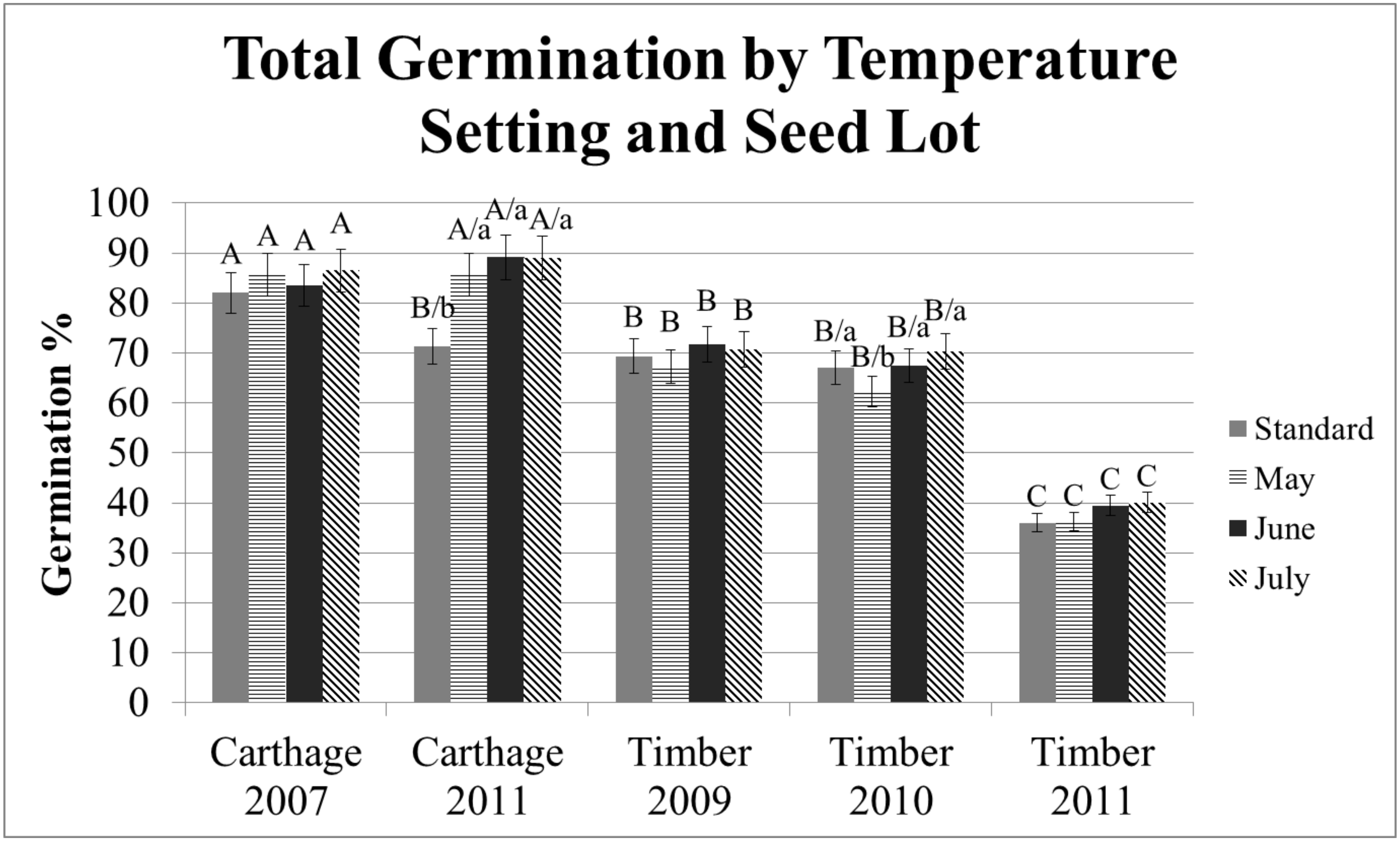


Figure 2. Total germination of five switchgrass seed lots evaluated in a growth chamber setting under various temperature regimes. Different lowercase letters indicate significant difference at $p < 0.01$ between temperature settings for each cultivar. Different uppercase letters indicates significant difference $p < 0.05$ between cultivars for each temperature setting.



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Chapter 5: Thesis Conclusion

The results of this research indicate a potential benefit in rototilling the field before planting switchgrass. Rototilling resulted in greater emergence and survival of switchgrass plants within the first harvest year. The benefits of additional field preparation would need to be weighed against the added cost of fuel and running the equipment. In addition, this research did not identify any long- term yield advantage by rototilling the field before planting.

Adding a compost amendment to the soil with a low C:N ratio had a positive effect on seedling emergence and survival ratings the first harvest year. A single application of this compost before planting had a significant effect on emerging seedlings. Additional research should be conducted to determine if additional annual applications continue to have a positive impact on the switchgrass stand. This experiment evaluated the effect of a single application, which did not have an effect on yield; however, annual applications could have a long- term effect on stand quality and should be evaluated to determine if there is an effect on dry matter yield production.

Research from the growth chamber study indicated that the overall rate of germination increases as the ambient temperature increases. This is an important factor to consider when trying to estimate the optimal planting date for growers in central New Jersey. Right now the recommended planting date is after May 15 and before June 15. Our research indicated an optimal planting date in July. An increase in germination rate might produce a more uniform switchgrass stand and could influence the amount of weed competition present in a field setting. However, we did not test whether a later planting date would influence winter kill and stand survival the following year after establishment. Further research would have to be conducted to determine the impact this particular variable has in relation to other variables impacting the success of a switchgrass stand at a particular planting date. The other variables that need to be considered are length of growth period after germination, weed competition at that particular time in the season and survival ratings of stands planted later in the season.

The five cultivars selected had various levels of success in stand establishment and dry matter yield during the first two years of establishment. To determine an accurate measurement of dry matter yields of mature stands of each cultivar in this region, yield data must be taken for an additional 3 to 5 years. This will provide a better estimate of the maximum yield potential for each cultivar. The stand may need to be evaluated for a longer period to account for the extreme variability in the weather patterns in central New Jersey. A longer data collection period will provide a more accurate estimate of average yields of these particular cultivars over a wider range of weather conditions that occur within this region.

Further research; investigating the highest yielding cultivars, most effective compost treatments and best planting date in Central New Jersey, is necessary to provide accurate information to local farmers. Increasing the annual yield and reducing the cost of production will allow for the highest profit margin. Each region within New Jersey can have different weather patterns, weed species and obstacles a switchgrass stand must overcome. Local trials should be conducted in each locality before the optimal planting date can be accurately determined.