FACTORS AFFECTING GRAPEVINE ESTABLISHMENT IN NORTHERN PRODUCTION REGIONS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Plant Sciences

March 2011

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Stenger, John Edward; M.S.; Department of Plant Sciences; College of Agriculture, Food Systems, and Natural Resources; North Dakota State University; March 2011. Factors Affecting Grapevine Establishment in Northern Production Regions. Major Professor: Dr. Harlene Hatterman-Valenti.

Two experiments were conducted to detect differences in growth and cold hardiness during establishment of northern grown wine grapevines. One experiment tested the use of four grow tube treatments and two pruning levels on vine establishment in the upper Midwest. The variables included leaf area, stem height, root growth, phenology, and hardiness. Overall, few significant differences occurred among treatments where grow tubes were utilized. In the second season, vines without grow tubes had superior measurements in nearly all leaf area categories. For this reason, it is recommended that growers refrain from grow tube use during establishment in northern growing regions. Vines pruned to three buds after transplanting varied little from those without pruning. For this reason, it is recommended that growers utilize the most efficient early pruning strategy for their particular situation.

Another experiment was conducted to determine the effectiveness of different weed control measures. This experiment compared three kinds of mulches and an herbicide treatment on the growth and establishment of four wine grape varieties. Annual weed control, plant growth, phenology, soil water content and temperature, and vine hardiness were measured. Overall, vines receiving mulch had more consistent annual weed control and reduced early season growth when compared to chemically treated vines. For this reason, mulch is recommended in the vineyard for annual weed control during establishment in situations where vigor is not unacceptably low.

ACKNOWLEDGMENTS

I would like to thank Dr. Harlene Hatterman-Valenti for all of her help during my undergraduate and graduate experience here at NDSU. She has been a great leader and mentor throughout my academic career, and for that I am grateful.

I would also like to thank Collin Auwarter, whose persistence and endless effort makes most of what is done in NDSU's High Value Crops project, including my evaluation trials, possible. His effort and input in the creation and maintenance of the trials involved in this study is greatly appreciated and will not be forgotten.

I would like to express my gratitude for the efforts of my graduate committee members, Drs. Ted Helms, Joe Zeleznik, Ed Deckard, and Donald Anderson. They have helped me in numerous ways throughout this experience as well as put much effort into editing this manuscript. I thank their support and efforts which have made this manuscript possible.

I would like to thank my wife Brianna for her support and aid when I have needed it. I would also like to thank her for all of her assistance in carrying out the research presented in this manuscript.

Lastly, I would like to thank my family. I thank my parents John and Mary for their constant support through my life and for making me into the person I am today. I would also like to thank my brother, Craig, and my sister, Kristy, for their help whenever I have needed it.

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INTRODUCTION

The goal of this study was to provide information that will allow northern wine grape producers to establish grapes more efficiently. The wine grape has become increasingly popular in the Midwestern region of the United States in recent years, including in North Dakota. This increase in popularity, which resulted in increased planted acreage and production, does not come without challenges. Traditionally, wine grapes (*Vitis vinifera*) are produced in coastal regions of the United States and Europe where winter temperatures are relatively mild (Patrice et al., 2006; Read et al., 2003). Hybridization breeding of *V. vinifera* with native, American species of grapes has enabled production by northern growers. This hybridization combines the high quality of the traditionally grown *V. vinifera* and the winter hardiness and disease resistance of the native species of grape. Though these hybrid grapes have increased hardiness, some still are insufficiently cold hardy in North Dakota when extreme conditions occur. The unknown dependability in winter survival of current varieties, coupled with the expense of vineyard establishment, causes financial uncertainty for growers during the critical establishment period of vine growth. If establishment of wine grapes could be improved through various cultural means, the feasibility and profitability to North Dakota viticulture would be improved as well.

To attempt to improve winter survival and growth in grapevine in the upper Midwest, grow tubes and pruning at transplant were investigated for their effects on growth and winter hardiness. These two practices have been said to improve grapevine growth and establishment. Though these are common practices in milder costal areas, their effects on grapevine culture have yet to be investigated in extremely cold environments, such as those found in North Dakota. Acclimation may be altered by utilizing these techniques, possibly resulting in reduced hardiness, and a net reduction in health and growth due to winter die back.

Weed control within establishing vineyards has also been challenging. Due the sensitivity of the grapevine to chemical weed control agents, spraying of vineyards to control weeds can be difficult as well as risky. Over half of the herbicides registered for use on grapes cannot be applied immediately after transplanting, with some requiring an interval of three years before application (Domoto, 2002). It is also thought that more efficient production may be facilitated through the use of mulches due to their soil water content and temperature manipulating properties. However, it is not known if the manipulation of soil water content and temperature will delay vine dormancy and subject plants to increased winter injury. For this reason, this study investigated the effects of one herbicide as well as organic and inorganic mulches on winter hardiness and growth during vineyard establishment

Improvement in the establishment of grapevines in cold climate production regions is necessary for continued growth of the northern wine industry. Through manipulation of production methods, northern wine grape producers will gain more control and stability in this new and emerging industry.

LITERATURE REVIEW

Grape production in the upper Midwest has increased in popularity in recent years. Through advancements in cultivars bred for cold hardiness, disease resistance, and quality, grape production has been made possible in areas once thought to be unavailable to growers. Currently, much progress has been made, but further breeding and production advancement is needed to stabilize the production process. The varieties that are offered to the upper Midwestern growers still remain unreliable in cold hardiness. One of the most economically critical times for producers is the unproductive establishment period. During this period vineyards require great financial inputs with no economic returns. Typically, this period is three to four years in more southerly locations, but in North Dakota it can take five or more years to harvest the first full crop from a newly established vineyard (Hatterman-Valenti, personal communication, February 6, 2009).

The Grapevine and its History

A grape is the fruit obtained from the perennial, woody, members of the *Vitis* genus of the *Vitaceae* family. Grapes are utilized for fresh eating, juices, preserves, as well as wines. Throughout human history, wine has had much significance being referred to in some cases as a drink of the gods (This et al., 2006). Wine was and still is utilized in customs of the Egyptians, Greeks, Christians, as well as many other cultural and religious groups for which it has great historical significance. For this, wine has become common place in human culture. Typically, wine is produced from selected cultivars derived from the *V. vinifera* species. *V. vinifera* originated from the western Mediterranean region and the Near East region (Arroyo-Garcia et al., 2006). In more recent history, American species of grapes were utilized as rootstock for *V. vinifera* due to complications from *V. vinifera*'s susceptibility to grape phylloxera (*Daktulosphaira vitifoleae*) (Granett et al., 2001). Grape phylloxera is an insect pest of grapevine species native to the Americas. Before the 1860s, grape phylloxera was transported overseas where it initiated a worldwide threat to the grape industry. The intolerant *V. vinifera* vineyards were damaged and destroyed by the invasive pest. The discovery of American *Vitis* species' tolerance enabled them to be utilized as rootstock, as straight species as well as hybrids containing *V. vinifera*. The American species of grapes later became important resources in the breeding of cold hardy, disease resistant grapes. Grape breeding programs are now utilizing germplasm from many different species including *V. cinerea, V. riparia* Michx, *V. labrusca, V. aestivalis, V. rotundifloria*, as well as others to increase disease resistance and expand the growing regions for wine grapes (Read and Gu, 2003).

Grow Tubes

Grow tubes have been utilized for many years in a variety of ways (fig. 1). When they are used to protect and speed the growth of trees they are considered tree shelters (Olmstead and Tarara, 2001). These tree shelters were designed to utilize their greenhouse-like effect to optimize environmental conditions for plant growth and production efficiency. Sunlight is allowed to pass through the semitransparent shelter and upon contact with the plant inside it is converted into heat. Though light is able to readily pass though the walls of the shelter, the heat created is less able to escape due to the insulating properties of the shelter and the restriction of air flow. Through this process, much like in a greenhouse, the shelter would theoretically increase in temperature during the day and be able to retain some heat for a given duration. Because this process is run by solar energy,

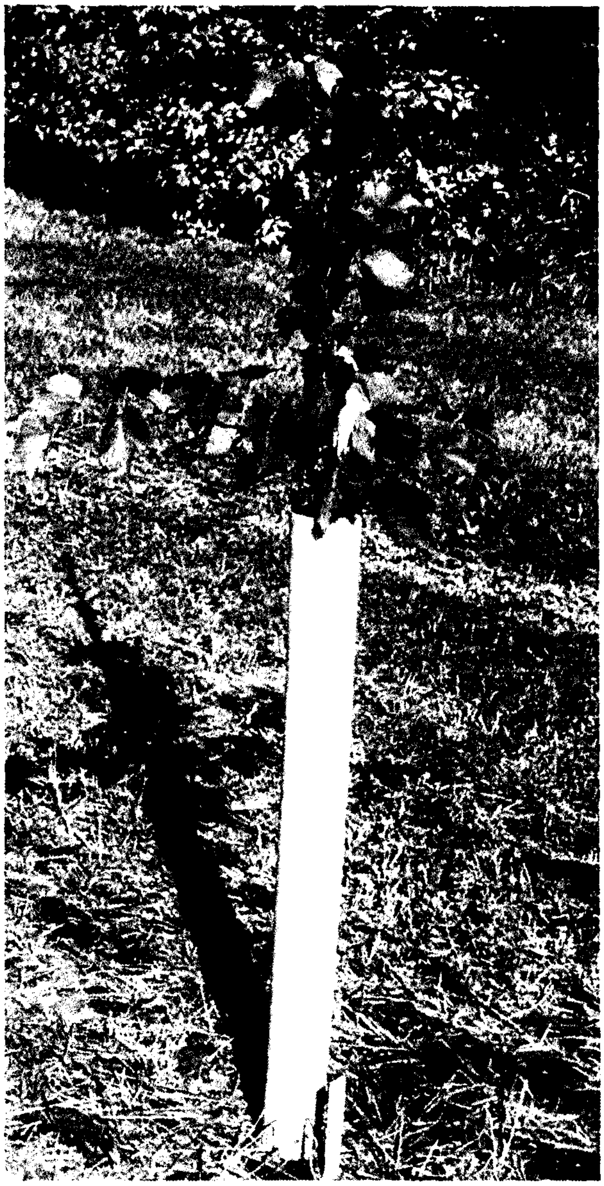

Fig. 1. Grow tube on a grapevine near Ekre, ND.

at night the internal temperature and the external temperature should equalize.

Grow tubes have been shown to improve vineyard management, environmental, and cultural conditions (Olmstead and Tarara, 2001). To improve the vines' growth, carbon dioxide concentration, temperature, and the environmental conditions affecting water use efficiency are altered. Optimum amounts of these conditions are required for maximum grapevine growth and health. In a related study conducted by West et al. (1999), ten species of trees were evaluated for height increases over a three year period. In this study, out of the 30 comparisons tested, there were only five comparisons where the sheltered trees' growth was not significantly greater than the unsheltered trees' growth. In all other cases the sheltered trees tended to show superior growth. Overall, it seems as though tree shelters caused greater growth, but the extent of the increase was species specific. In only one species was there a consistent similarity in growth between treatments over all three years. Three of the five instances were growth was not significantly effected by shelter use were in the comparison of Florida Maple in three separate years.

Though the goal of producers during the first years of establishment is to obtain the largest amount of growth for the creation of the trunk and cordons, the continuance of this growth late into the season could be deleterious. Grow tubes can have acclimation and dormancy delaying properties. Grapevines have indeterminate growth and require environmental signals to initiate acclimation to winter dormancy. Therefore, when favorable growing conditions are present, vines will continue vegetative growth. During periods of active growth, bud acclimation does not occur. The increased vegetative growth at the end of the growing season may shorten the time allowed for the slow gradual shift into winter dormancy. Temperature swings caused by daytime temperature increases with grow tubes, followed by night time temperatures falling to near ambient, may also delay dormancy (Olmstead and Tarara, 2001). In a study conducted by M. Hubáčková (1996), the hardiness of grapevines was found to be more closely correlated to the maximum and mean temperatures when compared to the minimum temperature that vines were exposed to prior to a freezing event. Grow tubes are thought to increase daily maximum temperature through the capture of solar energy, possibly lowering the plant's ability to withstand cold temperatures. Also, at times of low solar energy, low temperatures are thought to be near ambient within the tube. These times of low solar energy also increase the likelihood of low dips in ambient temperature. Increased temperatures with high solar radiation and ambient temperatures with low solar radiation may result in reduced overall vine hardiness without buffering vines from nighttime low temperatures. Increased temperature fluctuations that are created may also lead to reduced acclimation through raising the mean daily temperature. These fluctuations could inevitably result in decreased winter hardiness. It has been suggested by John Marshall (Personal Communication, February 9, 2008) that the lifting of the grow tube near the end of the season could reduce the deleterious effects on acclimation. This would allow for all of the benefits of grow tube use without the risks to grapevine survival and health.

In addition to providing improved environmental conditions for grapevine growth, grow tubes also provide cultural advantages over conventional vine establishment techniques (Olmstead and Tarara, 2001). One important advantage is in vine form control. Grapevines are forced to grow vertically with restricted horizontal growth due to the shape of the tube. This growth pattern is favorable for production systems because vines are forced into a vertical position for trellising and production. With the grow tube present, reduced amounts of staking and supporting of the vine is required. The tube also reduces wind speeds. This could aid in reducing broken branches and tattered leaves caused by wind early in the spring when new growth is fragile. This property is especially important in cultivars of grape that are prone to early cane breakage, such as 'Prairie Star' (Okie, 2002).

Another benefit to the use of grow tubes is the ease of weed control near the vines during establishment. Young grapevines with new growth are especially prone to herbicide damage (Domoto, 2002). This sensitivity to herbicides can make weed management in vineyards difficult especially during the establishment period when green growth occurs near ground level. Grow tubes have been thought to provide a physical barrier, which can reduce the amount of damaging herbicide that comes into contact with the vines as well as speed up the application process. Even though many producers within North Dakota have utilized grow tubes after transplanting grapevines, the increase of growth or actual benefit when grow tubes are used has not been investigated in extremely cold climates.

Pruning at Transplanting

Much control over growth can be achieved by pruning grapevines after transplanting. It is recommended that grapevines be pruned to approximately one stem containing 2-3 buds after transplanting (Dami et al., 2005). The implementation of this recommendation has become common practice though little experimentation has actually been done to validate its benefits. However, previous work has been done to evaluate the need to prune when transplanting bare-root deciduous trees. In a 1981 article, Shoup et al. investigated the effects of pruning at transplanting on various bare-root deciduous trees. This investigation stemmed from the wide spread use of pruning to attempt to equilibrate the balance of below ground biomass to above ground biomass by shortening shoots to compensate for root mass lost during plant digging. They found that pruning had no effect on plant size two years after transplanting. Pruning after transplanting was utilized to encourage increased vigor within the few retained buds to increase vertical growth. Grapevine growth, in many cases, eclipses the yearly growth of tree species due to grapevine's indeterminate nature. This may alter the effect of pruning after transplanting from previously tested tree species.

Since trunk establishment is the overall goal during the first year, increased vertical growth is beneficial. It is thought that increased vertical growth may be seen in pruned vines due to increased vigor in the few retained buds when compared to the further divided allocation of resources in un-pruned vines (Harris et al., 2004). Though increased growth is the goal in traditional grape production areas, it is unclear whether or not it is beneficial in the extreme environments of North Dakota. Though increased vertical growth may be seen, much of this is lost in North Dakota during the first establishment year due to winter dieback. It is also reported that rapid growth can reduce a plant's ability to acclimate tissues before the onset of low temperatures, thus suppressing the onset of dormancy (Kalberer et al., 2006). This causes decreased hardiness and reduced survival of tissues. In addition, if more buds are retained, increases in photosynthetic capability may be achieved through increased leaf area. Increased photosynthetic activity combined with reduced levels of growth could allow for better hardening off at the end of the season and overall healthier plants.

Winter Hardiness

Hardiness is the ability of a plant to survive cold temperatures. According to Ristic and Ashworth (1997), plants generally achieve hardiness in one of two ways. The first way is by supercooling. Supercooling is the process by which moisture from within the cell is allowed to escape to the intercellular spaces before freezing. This process causes the solute concentration within the cells of the plant to increase and become less prone to freezing. When ice forms outside of the cell it is generally considered to be harmless to the cell and little to no injury occurs. When temperatures continue to decrease to the point at which the supercooled solution within the cells freezes, ice crystals form within the cell. The formation of ice intracellularly causes damage to the cells. This inevitably results in the death of the cell and a portion of the plant's tissues.

The second explanation of how plants evade damage due to sub-freezing temperatures is by continuously losing water to the intercellular spaces as the temperature decreases to the extent that the cell deforms or collapses (Ristic and Ashworth, 1997). In this method, the hardiness of the cells within the plant is a function of the amount of secondary stress the cell can take. The stress that the cell endures during this period of dehydration includes reduction of the cell's volume, alteration of pH, precipitation of proteins, alteration of the membranes' osmotic abilities, and an increase of solute concentration within the cell. The eventual death of cells in this system is not due to the formation of ice within the cells, but to the stresses that dehydration of the cell brings.

The method by which grapevines are thought to endure cold temperatures is by the supercooling method (Fennell and Mathiason, 2002; Pierquet and Stushnoff, 1980). In this method there exist two exotherms (Ristic and Ashworth,1997). Additional non-damaging exotherms may exist due to the inconsistent water formation throughout the tissues within the vine (Pierquet and Stushnoff, 1980). The first exotherm, or series of exotherms, is called the high temperature exotherm (HTE) (Ristic and Ashworth, 1997). The HTE occurs at temperatures of -1 to -15 °C. This exotherm is associated with the freezing of extracellular water. This includes both the intercellular and xylem moisture. At this point the intracellular water remains unfrozen due to its supercooling ability provided by its solute content. The second exotherm occurs near the nucleation temperature (-38 °C) and is called the low temperature exotherm (LTE). At this exotherm the intracellular moisture freezes and causes cell death. Despite grapevines supercooling abilities, there is much variation within the genus in regard to hardiness. Many V. *vinifera* grape cultivars are tender, having cold hardiness ranges from -17.8°C (0°F) to -23.3°C (-10°F) (Dami et al., 2005). French-American hybrid vines have been known to be very hardy with cold hardiness ranges from -23.3°C (-10°F) to -37.2°C (-35°F). Plants of the species V. riparia have been known to have primary bud survival at temperatures below -40°C (-40°F) (Pierquet and Stushnoff, 1980).

The ability to withstand the lowest temperature in an area does not determine plant survival because the acclimation-deacclimation process is also very important to plant survival in a certain location (Kalberer et al., 2006). Acclimation is the process by which a plant increases its level of hardiness. This process is complex and is regulated by the build up and alteration of many substances and structures within the cell including the cell membrane, carbohydrates, proteins, and enzymes. Deacclimation of a plant, conversely, is the reduction in a plant's ability to withstand cold temperatures that leads toward the elimination of dormancy and the reactivation of growth. The acclimation-deacclimation process, though needed to gain hardiness, can be considered a separate function from low temperature hardiness. This is to say, though a grapevine may be considered hardy at a given low temperature under optimum conditions, the same plant could be injured at a much higher temperature if it has not acclimated properly or has deacclimated too quickly. Many varieties of grapevine are listed as being hardy to below -40°C. This should be adequate for consistent hardiness in North Dakota. However, winter injury has been reported in these varieties when winter low temperatures have been above -40°C (Hatterman-Valenti, 2009). This leads to the conclusion that these varieties should be able to withstand North Dakota's low winter temperatures, but cannot due to improper acclimation or improper deacclimation. The low temperature hardiness a plant can withstand may not be realized if the plant is not allowed or cannot acclimate and remain acclimated.

The acclimation-deacclimation process of a plant can be affected by environmental as well as cultural conditions. In situations where conditions are favorable for vegetative growth, such as high nitrogen, high moisture, and warm temperatures, dormancy is suspended in favor of vegetative plant growth. In conditions of stress, such as low nitrogen, drought, and cool temperatures, vegetative growth is suspended and dormancy is encouraged. This acclimation process takes time. Acclimation requires a long, slow shift to allow for the maximum level of hardiness. Thus, when dormancy is encouraged early, the plant has ample time acclimate before cold temperatures arise. When the acclimation process is postponed later into the growing season, less time is available which can result in a lowered or insufficient level of hardiness. In a similar vein, when unseasonably warm growing conditions arise in the early spring, deacclimation can occur too rapidly. If this deacclimation period is followed by a return to cold temperatures, injury can occur. Both increased temperature as well as increased fluctuation in temperature can lead to decreased acclimation or increased deacclimation resulting in an increase in winter injury.

Phenology

Phenology, coming from the Latin *phaino* meaning to show or appear, is the study of lifecycle periodicity based on seasonal events (Rathcke and Lacey, 1985). The event evaluated in this study was the initiation of growth. After spending months in dormancy to escape harsh winter conditions, grapevines resume growth in the spring by the breaking of dormant buds that were created during the previous season. Buds created in the previous summer become endo-dormant through the cessation of growth in preparation for winter (Mathiason et al., 2008). The endo-dormancy is caused by internal factors within the vine that discourage growth. The endo-dormancy is released with the fulfillment of a required amount of chilling time, or a number of hours below a specified temperature. Once the endo-dormancy is released, the buds remain dormant due to eco-dormancy or environmentally induced dormancy. Eco-dormancy allows the bud to remain dormant until favorable environmental conditions for growth occur. Since the onset of favorable growing conditions is environmentally based, cultural practices that affect the microclimate around vines could affect the phenology by either hastening or delaying bud break. Many of the cultural treatments tested in this study are meant to alter the growing environment of vines to manipulate growth and hardiness. Testing for alterations in the phenological pattern is necessary due to the importance of phenology on grapevine growth and survival. If bud break is hastened it is possible that growth is initiated too early causing damage to tender new growth by early spring frosts. Excessive delay of growth, though it reduces the chance of early spring frost injury, may shorten the already short growing season of the area. A reduced growth period may translate into reduced growth rates and longer establishment times.

Weed Control

To ensure the sufficient growth of grapevines during their establishment period, weeds must be controlled. Weeds compete with grapevines for water, nutrients, as well as sunlight (Dami et al., 2005). For this reason, the presence of weeds reduces the health and growth of grapevines. Traditionally, weeds in vineyards are controlled by tillage and chemical means. Though these weed control methods are efficient, they may damage vines when utilized incorrectly. Tillage may disrupt the root system, increase water loss, and increase soil dispersion. Chemical control is not without risk. Grapes have been found to be particularly sensitive to many of the commonly utilized turfgrass herbicides (Dami et al., 2005). Grapes show damage from foliar contact with 2,4-D and glyphosate as well as many other commonly utilized post emergent herbicides. Glyphosate is particularly problematic due to its wide use in complete, non-selective vegetation control. Though grapevines are not harmed when glyphosate is applied to mature wood with bark, any green tissue allows for entry into the plant. Even if care is taken to avoid spraying leaves, spray droplets may land on unseen emerging buds and suckers near the base of the plant. Since this is a systemic herbicide, the chemical is then transported throughout the plant. Though this small amount of herbicide taken up by the plant may not cause death, in many cases it causes deformation and loss of leaves, persistent depressed growth, and fruit loss (Longstroth, 2008). For this reason, lower-risk options for weed control have been investigated for their effectiveness in weed control as well as their effect on vine growth and hardiness.

Herbicide

Herbicides have become the leading weed control option in most agronomic, vegetable, and fruit production systems (Ozores-Hamptom et al., 2001). The increase and near absolute use of herbicides stems from their ability to reduce labor costs compared to other options. Herbicides have become the leading pesticide input in cropping systems due to the production limitation caused by high levels of weed growth and the ease of herbicide applications. In recent years, concerns about the high level of herbicide use and their potentially harmful effects on humans and the environment have been raised. These concerns about human and environmental health have resulted in the placement of restrictions by the Environmental Protection Agency (EPA) on the use of many herbicides that were once common. Thus, research for viable, sustainable alternatives to herbicide use has been ongoing.

In grape production, additional limitations exist in post emergent herbicide options, due to the susceptibility of vines to herbicide damage at very low concentrations. In North Dakota, the most common post emergence herbicide in the vineyard for within-row weed management is glyphosate (Hatterman-Valenti, 2008). Glyphosate (N-(phosphonomethyl)glycine) is a non-selective systemic herbicide capable of controlling annual and perennial grasses and broadleaf weeds (Duke and Powles, 2008). Glyphosate's systemic and non-selective characteristics are great strengths which resulted in it becoming the most used herbicide worldwide. Adding to glyphosate's popularity are its low human toxicity and low probability of leaching. Preserving the use and efficiency of this herbicide is important. A key practice to prolong glyphosate's effectiveness is to reduce its use. Diversity in weed control is important in reducing the evolution of glyphosate resistance. Reduction in selection pressures reduces the chance of resistance, allowing for the continued use and efficiency of glyphosate. Though glyphosate is important in controlling weeds in North Dakota vineyards, its longevity and effectiveness may depend on its utilization as a part of an integrated system.

Mulches

As an alternative weed control measure, the use of various mulches has been suggested. Mulch has been utilized as a weed depressant for many years in many crops and ornamental applications (Derr and Appleton, 1989; Smith et al., 2000). Three common mulches (landscape fabric, straw and woodchips) were investigated for their ability to control weeds and alter soil conditions, which in return may alter grape growth during establishment.

Landscape fabric has been utilized both in ornamental landscape plantings as well as in field fruit and vegetable production for weed control (Derr and Appleton, 1989). Landscape fabric kills weeds by blocking needed sunlight for proper growth and development, thus effectively smothering weeds. However, the use of landscape fabric is not without risks. Most landscape fabric is black in color and absorbs heat. This may speed the initiation of growth in the early spring, making the vines more susceptible to frost damage. Also, increased heat in the soil could cause reduced onset of dormancy at the conclusion of the year. In both instances, decreased levels of winter hardiness may occur. This would most likely increase the duration of unproductive establishment time.

Straw and woodchip mulches are being investigated as uses for otherwise unutilized debris in cropping and urban areas (Smith et al., 2000). In many instances these materials can be obtained inexpensively or free. Baled straw is easily stored, easily handled, and widely available thus making it a good option for mulch. Straw and woodchip mulches are lighter in color as well as more reflective than landscape fabric, thus may have reduced levels of soil heat and reduced risk of early initiation and late season cessation of growth. Since these mulches are lighter in color than most soil, the opposite may occur. It is possible that the reflection of solar radiation may delay bud break. However, in both of these treatments, there is still concern about the delay of growth cessation. Both treatments should increase soil water content due to the mulch's soil water content conservation effects. This increased water may cause favorable conditions for growth late into the season, thus reducing the ability of the vine to initiate acclimation. This could allow for increased winter damage and overall decreased hardiness. Lastly, straw and woodchip mulches may not provide continuous cover, compared to landscape fabric, thus these treatments may have reduced effectiveness in controlling weeds.

Whether based on organic or inorganic materials, all mulches control weeds by smothering them. Once the layer of mulch is applied, its effectiveness generally remains unless the mulch is eliminated or reduced allowing for weed seed soil contact and light needed for growth. Mulch is only effective as long as it is maintained.

Mulches have been shown to have additional benefits beyond weed suppression. Mulches may improve soil water content, reduce soil erosion, and reduce soil compaction (Dickerson, 2001). The additional moisture could increase the growth and health of vines through establishment. If enough moisture is conserved, savings to producers in low rainfall regions could be realized.

OBJECTIVES

The objectives of this experiment are to evaluate cultural methods to improve early growth, increase hardiness, and reduce winter injury in grapevines after transplanting. Through this experiment the following questions will be answered: How do grow tubes and pruning at transplanting affect plant growth and winter hardiness in grapevines during establishment? Do herbicide or mulching treatments significantly impact grapevine growth, hardiness, weed control, or phenology during establishment? Are there management practices that would enable more consistent, rapid establishment of grapevines beyond what is currently seen by northern growers by altering growth rate and winter hardiness? Do treatments that beneficially alter vine growth and winter hardiness differ significantly in weed control, plant height, and number of stems?

CHAPTER I.

EFFECT OF GROW TUBE USE AND PRUNING AT TRANSPLANTING ON GRAPEVINE ESTABLISHMENT IN THE UPPER MIDWEST

Introduction

Research on vineyard establishment methods has been lacking in the upper Midwestern United States. This need stems from an increasing trend toward locally grown wine grapes in northern regions. Drawing from breeding breakthroughs by a number of contributors, upper Midwestern viticulture has been made possible by the introduction of hardy wine grape cultivars (Read and Gu, 2003; This et al., 2006; Luby et al., 2007). These cultivars are generally complex crosses involving American and Eurasian grape species. Most commonly, the European species *Vitis vinifera* is crossed with American species of grape, such as V. *labrusca*, *V. riparia*, *V. aestivalis*, *V. rupestris*, and *V. cinerea*, as well as others, to produce interspecific hybrids (Read and Gu, 2003; This et al., 2006). The *V. vinifera* grape species passes fruit quality traits that are needed for wine production. The American species generally provide genetics strong in hardiness and disease resistance (Read and Gu, 2003). Through the combination of these traits, quality wine is increasingly produced in the upper Midwest.

Despite advances in production, problems still exist. The hybrid varieties currently grown in the upper Midwest were bred in areas in the southeastern portions of the Midwest

(Read and Gu, 2003; This et al., 2006; Luby et al. 2007). Also, much of the lineage of these varieties was derived from grapes grown in more southern and coastal regions, causing these varieties to be less fit outside their intended geographical range (Kalberer et al., 2006). For these reasons, the hybrid grape varieties used in upper Midwestern viticulture tend to show insufficient hardiness when large, quick shifts in temperature or unseasonably high or low temperatures occur during the dormant season.

Many practices are claimed to improve growth in grapevines during establishment. One such practice is the use of grow tubes. Grow tubes, also known as tree shelters, are utilized to improve plant growth by acting as a miniature greenhouse surrounding the plant. Grow tubes have been shown to increase the growth of many plants, particularly in height. It is thought that if the size of the plant can be increased more rapidly, less time should be required to establish grapevines and produce a saleable crop.

Though it is thought that grow tubes alter the microclimate around vines beneficially, the artificially created conditions could potentially hinder survival of dormant vines by suppressing the onset of dormancy. A reduction in time for acclimation to occur would most likely result in lower hardiness. This would potentially lead to increased winter damage.

Another method by which the rate of growth is increased is through pruning at transplanting. It is recommended that grapevines be pruned to two to three aboveground buds when transplanted (Dami et al., 2005). This is to increase the vigor in the few retained buds enabling increased vertical growth. Increases in growth can aid in trunk establishment. Typically all other lateral growth is removed to support only one or two stems. This allows for cordon (vine branches where fruit will be borne) development in subsequent years. In a study conducted by Shoup et al. (1981), no evidence was found supporting this commonly utilized technique in deciduous trees. They found that no significant differences existed between bare-root trees, some of which had been pruned while others were not pruned, after two years. Though the growth of grapevine is potentially much different than that of deciduous tree species, further investigation of the effects of pruning at transplanting on early growth should be investigated.

The conditions faced by northern viticulturists are much different than those found in more moderate coastal regions. One of the most prominent differences is the low temperatures experienced in the upper Midwest. For example, it is not uncommon for winter temperature lows to be below -35 °C. These excessively low temperatures cause great stress on plants and can also result in injury. Another environmental challenge in the upper Midwest is the amount and speed by which weather conditions change. In costal areas, slow gradual shifts in weather conditions are predominant. In the upper Midwest, relatively large temperature shifts can occur in a matter of days if not hours. This causes unpredictable early and late season frost dates that are critical for effective wine grape production. Large shifts in temperature can also reduce grapevine dormancy, not allowing for adequate cold hardiness to develop.

If improved early growth and survival can be achieved, greater economic stability could be realized by upper Midwestern grape producers. For this reason, growth tubes and pruning at transplanting were investigated for their effects on grapevine growth, hardiness, and phenology during vineyard establishment in the Red River Valley.

Materials and Methods

Trial Locations

Three trials were initiated to evaluate the effect of grow tubes and pruning at transplanting on grapevine growth, hardiness, and phenology. The first trial was established in June of 2008 and was observed through May of 2009 at an NDSU research station near Absaraka, ND. A second trial was established May of 2009 and was observed through July of 2010 at a separate location within the same research station near Absaraka, ND. The final trial was established May of 2009 and observed through July of 2010 at a farmstead near Glyndon, MN. All trials were planted with the cultivar 'Prairie Star'. 'Prairie Star' is a cold hardy (-35 °C), white wine variety that is commonly grown in the Midwest (Clark, 2002). This variety was introduced in 2000 by Elmer Swenson, from Osceola, Wisconsin, and was never patented. One of the reasons this cultivar was selected above others was that it is suspected to be winter hardy enough to survive typical North Dakota winters without protection, but is not very vigorous during establishment. This suggests that during average years in the area, vines without treatments should have relatively small amounts of winter damage. In addition, this cultivar is known to establish poorly; thus, treatments that promote growth should be beneficial.

The trials were similar, but were randomized separately. Each trial consisted of vines spaced 2.4 meters (8 feet) apart in rows placed 3.1 meters (10 feet) apart. The 2008 Absaraka, ND trial consisted of twelve rows containing sixteen plants each with a north to south orientation. The 2009 Absaraka trial consisted of seven rows with each row containing twenty-eight plants each (exception being the final row with twenty-four plants) with an east to west orientation. The Glyndon trial consisted of four rows with each row containing forty-eight plants, with a north to south orientation. At each location, the trial was divided into six replicates.

Each trial contained eight treatments as listed in Table 1 for the 2008 Absaraka, ND location and Table 2 for the 2009 Absaraka, ND and 2009 Glyndon, MN locations. When grow tubes were removed in the fall, the removal was in mid-August prior to leaf drop. When tubes were lifted for the winter, the lift occurred after leaf drop and before snow accumulation. Each experimental unit was represented by four linearly adjacent vines planted within a row. Data was averaged for all vines within each experimental unit. The average value was used for each experimental unit during statistical analysis.

The 2008 Absaraka, ND trial was planted on a Warsing sandy loam soil categorized as frigid oxyaquic hapludolls (National Cooperative Soil Survey, 1999). This site had mixed perennial grasses prior to the start of the study that were killed with a combination of glyphosate and tillage. This trial was abandoned due to overland flooding in the spring of 2009, which caused sporadic and delayed bud break.

The 2009 Absaraka, ND trial was planted on a Warsing sandy loam soil transitioning to a Swenoda fine sandy loam soil toward the west (National Cooperative Soil Survey, 1999). This soil transitions from frigid oxyaquic hapludolls to coarse-loamy, mixed, superactive, frigid pachic hapludolls in the west. Prior to the establishment of the trial, the site had medicinal purple coneflower (*Echinacea* sp.) and valaria (*Valeriana officinalis)* production trials, which were killed with a combination of glyphosate and tillage.

Table 1. Grape establishment trail treatments in 2008.

Treatment name	Transplanting description	Pruning level	Grow tube factor
Pruning- industry recommended	One node below ground	Pruned to three buds at transplanting	None
No pruning	At level dug from the nursery	None	None
Pruning to one stem	At level dug form the nursery	To one stem throughout the season	None
Pruning to two stems	At level dug from the nursery	To two stems throughout the season	None
Grow tube – full year	At level dug from the nursery	None	Full year
Grow tube – full year with fall lift	At level dug from the nursery	None	Full year, lifted 30.5 cm (12 in.) above the ground in fall
Grow tube – fall removal	At level dug from the nursery	None	Removed in fall
Grow tube – industry recommended	One node below ground	Pruned to three buds at transplanting	Full year

The 2009 Glyndon, MN trial was planted on a Wheatville silt loam soil (National Cooperative Soil Survey, 1999). This soil is defined as a coarse-silty over clayey, mixed over smectitic, superactive, frigid aeric calciaquoll. This trial was planted into wheat in the spring of 2009. The wheat was killed with glyphosate within rows post transplanting, and was mowed between rows for the duration of the season. Glyphosate was used periodically to control perennial weed species between rows.

Table 2. Grape establishment trial treatments in 2009.

Grow tube factor	Pruning level
None	To three buds
None	None
Fall removal	To three buds
Fall removal	None
Full year	To three buds
Full year	None
Full year, lifted 30.5 cm (12 in) above ground in fall	To three buds
Full year, lifted 30.5 cm (12 in) above ground in fall	None

The trials were managed as typical Midwestern vineyards. At the beginning of the second season, all vines were treated equally as all grow tube treatments were removed and vines were pruned and trellised into a high cordon system. Even though the 2008 Absaraka trial was abandoned in the spring of 2009, data was collected in the evaluation of winter temperature differences among treatments for the winter of 2008-2009.

Stem Growth

Average total leaf area per vine was determined mid July 2009 and 2010. Individual leaf areas were determined by collecting the fourth expanded leaf from each plant within each experimental unit. The number of leaves for each plant was quantified by direct count. The leaves obtained from each plant were scanned using Leafarea Measurement software (version 1.3, Copyright 2003) from the University of Sheffield. Average values of both individual leaf area and leaf number were calculated. The estimated total leaf area for each treatment was calculated as:

Total leaf area per plant = average leaf area x average number of leaves per plant

Stem number was also counted to determine if resources were allocated differently among treatments for aboveground growth patterns.

Due to deer herbivory at the Glyndon location, which confounded treatment measurements, data was not utilized in the evaluation of the leaf area tests. Thus, only the 2009 Absaraka trial was analyzed for leaf area, leaf number, stem number, and estimated total leaf area parameters in both 2009 and 2010.

Height measurements were taken in the fall after the cessation of growth. Height was measured from the base of the trunk of each plant to the tip of the tallest stem.

Winter Temperature

In the winter of 2008 to 2009 and the winter of 2009 to 2010, temperatures were monitored next to vines with grow tubes for the entire winter, vines with grow tubes lifted for the entire winter, and vines without grow tubes. Data loggers were used to store temperature readings from thermisters placed near the vines in the middle of the tubes or the same location when grow tubes were not present. The 2008 Absaraka, ND trial was recorded every two hours from October 2, 2008 through December 22, 2008 and from March 2, 2009 through April 22, 2009. Data was taken for five vines with tubes for the full season, five vines with lifted tubes, and four vines with no tube. Data was averaged over all vines within each treatment. The 2009 Absaraka, ND trial was recorded every two hours for six vines of each treatment from December 18, 2009 through April 28, 2010. Data for the six sampled vines within each treatment was averaged. For both trials, daily average temperature, high temperature, low temperature and temperature fluctuation were calculated. The data sets were visually inspected for any differences. No ANOVA was performed on this dataset as only supportive information was received.

Root Growth

To determine the effect of each of the treatments on root growth, soil core sampling was utilized. A pickup mounted hydraulic probe (Giddings Machine Company Inc. Windsor, CO) was utilized in taking the core samples. In the fall of 2009, the first plant within each experimental unit of each replication for the 2009 Absaraka, ND and Glyndon, MN trials was sampled. Eight cores were taken near each sampled plant (Fig. 2). Five linear samples were taken 45.7 cm (1.5 ft) away from the vineyard row and spaced 30.5 cm (1 ft) apart. A second linear row of three samples was taken 91.4 cm (3 ft) from the vineyard row and spaced 30.5 cm (1 ft) apart. Both linear sampling rows were centered from the position of the test vine. All core samples were taken to a depth of 114.3 cm (3 ft 9 in) with a diameter of 4.5 cm (1.75 in).

Roots were extracted from the samples utilizing an extraction method similar to that utilized by Perry et al. (1983). All cores taken from each plant were combined. A 3.5g/l

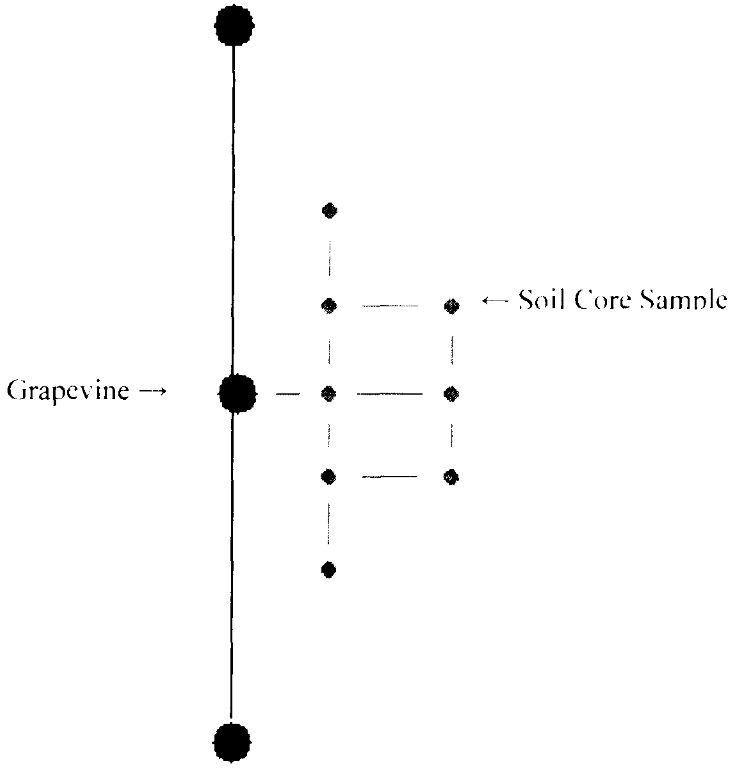

Fig. 2. Core sampling pattern at Absaraka, ND, and Glyndon, MN, for root growth analysis.

concentration sodium hexametaphosphate solution was added to cover the soil sample to aid in deflocculating the soil and ease root extraction. Samples were soaked in the sodium hexametaphosphate solution for at least 24 hours. The soil was then sieved through a screen mesh under running water to remove soil from the larger coarse soil constituents and organic matter.

Grape roots were separated visually from the remaining coarse soil material and organic matter based on morphological comparison to a known sample. Only roots with diameters of less than 1 mm were evaluated to increase accuracy. Larger roots can be infrequent and could cause bias. Roots were analyzed for their total length of fragments obtained, surface area of fragments obtained, volume of fragments obtained, average root diameter, and total number of tips in fragments obtained using WinRhiZo software (Regent Instruments Inc. Ottawa, ON Canada) and a Epson Perfection V700 Photo Scanner (Seiko Epson Corp. Owa, Suwa, Nagano Japan).

Phenology

In the spring of 2010, the timing of bud break was determined. The date at which the first unfurled leaf was seen for each plant was also recorded. In this experiment an unfurled leaf was defined as a leaf that has completely opened from the growing point, but has not enlarged in size. Observations were made twice per week (approximately 3-4 days apart). Observation dates were converted into Julian Days.

Winter Hardiness

The treatment effect on vine hardiness was evaluated in the spring of 2009 and 2010. For each plant, height was measured in the fall of 2009. In the spring of 2010, the total number of nodes, total number of viable nodes, height to the tallest viable node, and vine survival were evaluated. Total number of nodes was measured as the total number of nodes on a single vine by direct count of nodes containing either viable or non-viable buds. Total viable buds were measured by counting the total number of nodes with viable buds on a single vine showing growth in June of 2010. Vine heights to the tallest viable node were measured from ground level to the highest point on the vine showing active growth in June of 2010. Vine survival was the percentage of vines in each experimental unit to show any growth in June of 2010. To obtain the percent of node survival the following equation was used:

Node survival (%) =

(total viable nodes / total nodes present) * (100)

To obtain the percent of height retention the following equation was used:

Height retention (%) =

(height to the tallest viable node spring, 2010 / height of vine fall, 2009) *(100)

Statistical Analysis

The experimental design at each location was a randomized complete block design (RCBD) with a factorial arrangement. For all datasets, treatment was evaluated as a fixed effect. When locations were combined, location was treated as a random effect. In all cases where percentages were evaluated an arcsine transformation was applied to the data prior to statistical analysis. Analysis of Variance (ANOVA) was completed using SAS 9.1 statistical software (SAS Circle P.O. Box 8000, Cary, NC 25712-8000). Treatment means were separated, where appropriate, using Fisher's Protected LSD at the 0.05 level of significance.

Results

Stem Growth

The 2009 Absaraka, ND trial was evaluated for treatment effects on leaf area parameters. In 2009, there were no significant differences among grow tube treatments for midsummer shoot and leaf data (Table 3). For single leaf area, number of leaves, number of shoots, and estimated total leaf area, all grow tube treatments were statistically similar. However, in the evaluation of pruning level, vines that were not pruned had significantly more leaves, shoots, and estimated total leaf area than vines that were pruned.

Leaf area was evaluated in 2010 in Absaraka, ND. There was an interaction between grow tube use and pruning level for single leaf area (Table 4). This interaction was graphed (figure not shown) to determine it was a true interaction. Significant differences occurred among treatment interactions.

Table 3. Effects of grow tube treatment and pruning level on leaf and vine growth parameters in July 2009 at Absaraka, ND.

Grow tube treatment	Single leaf area	Number of leaves	Number of shoots	Total leaf area
	---- mm^2 ---	------ no. ------	------ no. ------	------ mm^2 ------
None	6,090	35.2	5.0	211,000
Fall removal	6,870	33.4	4.6	230,000
Full year	6,670	34.9	5.0	234,000
Fall lift	6,940	34.7	4.8	241,000
LSD (0.05)	ns[y]	ns	ns	ns
Pruning level	------ mm^2 -- ---	------ # ------	------ # ------	------ mm^2 ------
None	6,450	39.2 a[z]	6.1 a	253,000 a
Pruned	6,840	29.9 b	3.6 b	205,000 b
LSD (0.05)	ns	3.8	0.6	35,100

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

There were no interactions between grow tube use and pruning levels for number of leaves, number of shoots, and total leaf area in 2010. Significant increases in number of leaves, number of shoots, and total leaf area occurred in the vines that were not tubed versus vines that were tubed (Table 5). Pruning levels were not statistically different for number of leaves, number of shoots, or total leaf area.

Vine height was evaluated after the cessation of growth in the fall of 2009. With all locations combined, vines that were tubed had significantly more growth when compared to vines that were never tubed (Table 6). In addition, pruning level did not significantly affect vine height.

Table 4. Effect of grow tube treatment and pruning level on single leaf area in July 2010 in Absaraka, ND.

Grow tube treatment	Pruning level	Single leaf area
		--------- mm^2 ---------
None	None	8,110 abcd[z]
None	Pruned	8,490 ab
Fall removal	None	6,270 e
Fall removal	Pruned	8,190 abc
Full year	None	6,760 cde
Full year	Pruned	6,670 de
Fall lift	None	9,390 a
Fall lift	Pruned	7,770 bcde
LSD (0.05)		1,550

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

Table 5. Effect of grow tube treatment and pruning level on leaf number, shoot number and total leaf area in 2010 at Absaraka, ND.

	Number of leaves	Number of shoots	Total leaf area
Grow tube treatment	-------- no./plant--------	--------- no./plant ---------	------- mm^2 -------
None	149.3 a[z]	6.2 a	1,246,000 a
Fall removal	90.9 b	3.6 b	689,000 b
Full year	80.6 b	2.7 b	615,000 b
Fall lift	91.7 b	3.0 b	803,000 b
LSD (0.05)	21.6	1.0	240,000
Pruning level	-------- no./plant --------	--------- no./plant ---------	------- mm^2 -------
None	108.0	4.2	848,000
Pruned	98.2	3.5	828,000
LSD (0.05)	ns[y]	ns	ns

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

Winter Temperature

Winter temperature was graphically evaluated to add support to hardiness data. No experimental statistics were calculated, and only trends were evaluated to draw conclusions. Multiple data loggers were averaged for each treatment. Missing data from late December though early March in the winter of 2008-2009 was due to the removal of the data loggers to protect them from damage due to excessively cold temperatures. Average winter temperature was graphically evaluated for trends during the winters of 2008-2009 and 2009-2010 (Figs. 3 and 4).

Table 6. Effect of grow tube treatment and pruning level on plant height combined over locations 2009.

Grow tube treatment	Fall shoot height
	---------- cm ----------
None	67.8 b[z]
Fall removal	135.3 a
Full year	141.6 a
Fall lift	139.4 a
LSD (0.05)	27.4
Pruning level	---------- cm ----------
None	120.4
Pruned	121.6
LSD (0.05)	ns[y]

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

The effect of grow tube use on daily high temperature was also investigated for trends in the winters of 2008-2009 (Fig. 5) and 2009-2010 (Fig 6). This data was to gain insight specifically on treatment effect on increasing day time temperatures, due to the warming properties of grow tubes.

Daily minimum temperature was also evaluated for general trends in the winters of 2008-2009 (Fig. 7) and 2009-2010 (Fig. 8). This data was utilized to gain support for any indication that grow tubes allowed or prevented any sudden decreases in winter temperature.

From daily maximum and minimum temperatures, a daily temperature fluctuation value was calculated. Daily fluctuation in temperature was evaluated for treatment trends in the winters of 2008-2009 (Fig. 9) and 2009-2010 (Fig. 10). This data is to help explain differences in temperature fluctuations between treatments that may have affected plant winter hardiness.

Root Growth

Data was found to be combinable over locations for average root diameter, but non-combinable due to heterogeneous variances in all other root growth parameters. No significant differences were found among any treatments in regard to root growth characteristics (Tables 7, 8, and 9). None of the root traits evaluated showed any increase or decrease due to a particular treatment.

Phenology

Data for date of bud break was homogeneous over locations, thus the two locations data were combined for evaluation. No significant differences were found in bud break date in 2010 due to either grow tube use or pruning level (Table 10).

Winter Hardiness

No significant differences were detected in grow tube use or between pruning levels in the spring of 2010 for winter survival. The number of surviving plants was similar across treatments (Table 11).

Table 7. Effect of grow tubes and pruning level on root fragment length, surface area, volume, and number of tips in Absaraka, ND, 2009.

Grow tube	Length	Surface area	Volume	Tips
	---- cm ----	---- cm^2 ----	---- cm^3 ----	---- no. ----
None	34.9	4.74	0.0565	108.9
Fall removal	75.6	15.00	0.2660	179.2
Full year	43.1	7.20	0.1063	93.9
Fall lift	20.6	2.48	0.0267	66.3
LSD (0.05)	ns[z]	ns	ns	ns
Pruning level	---- cm ----	---- cm^2 ----	---- cm^3 ----	---- no. ----
None	39.9	6.35	0.0885	100.2
Pruned	47.2	8.36	0.1392	124.0
LSD (0.05)	ns	ns	ns	ns

[z] ns = not significant.

Table 8. Effect of grow tubes and pruning level on root fragment length, surface area, volume, and number of tips in Glyndon, MN, 2009.

Grow tube	Length	Surface area	Volume	Tips
	---- cm ----	---- cm^2 ----	---- cm^3 ----	---- no. ----
None	40.5	6.41	0.0852	127.1
Fall removal	27.7	5.28	0.0830	63.8
Full year	35.6	6.82	0.1139	94.3
Fall lift	48.0	8.20	0.1187	149.3
LSD (0.05)	ns[z]	ns	ns	ns
Pruning level	---- cm ----	---- cm^2 ----	---- cm^3 ----	---- no. ----
None	35.6	6.20	0.0878	98.5
Pruned	40.3	7.16	0.1125	118.8
LSD (0.05)	ns	ns	ns	ns

[z] ns = not significant.

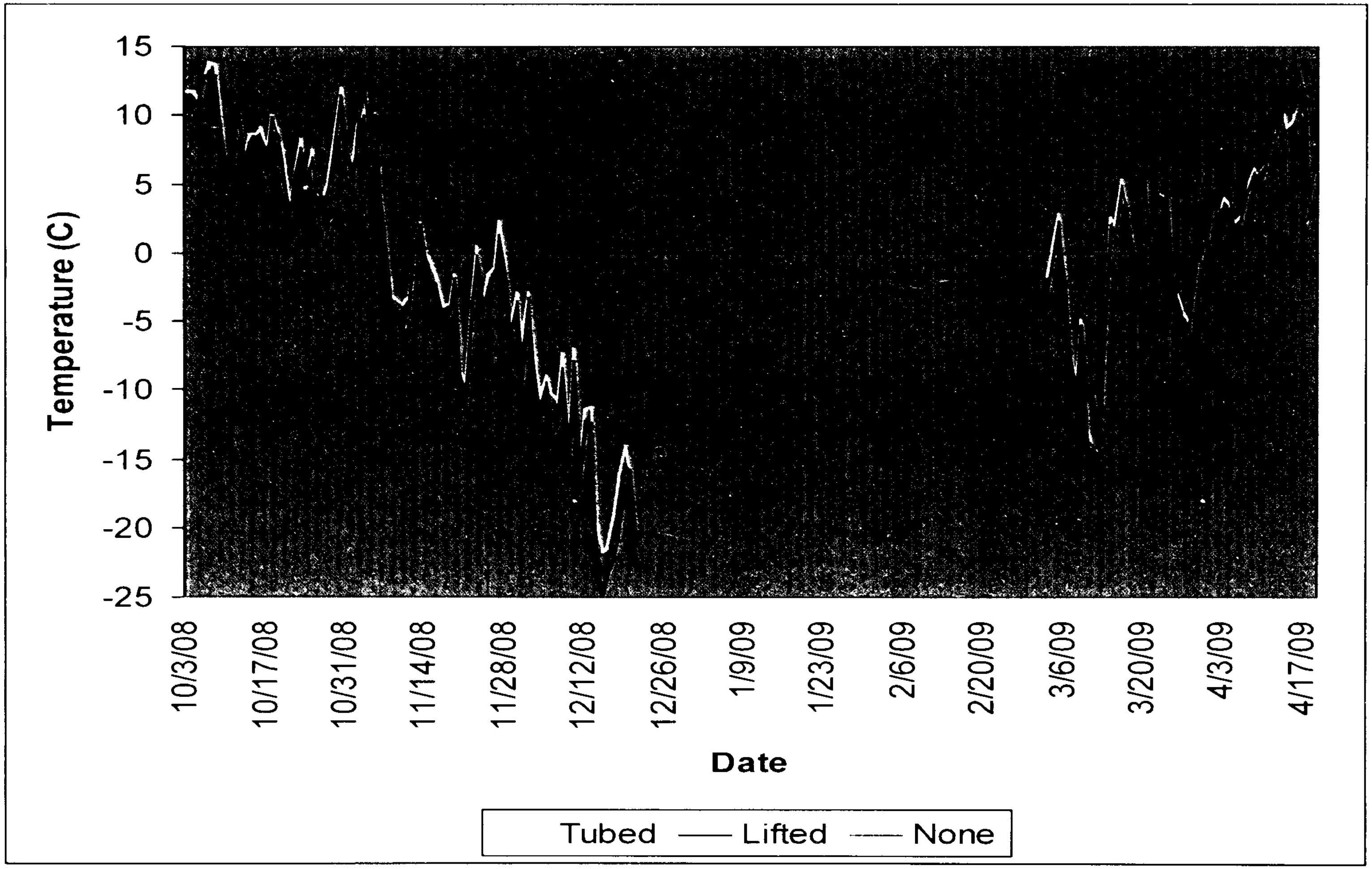

Fig. 3. Effect of grow tube treatment on daily average temperature in 2008 and 2009.

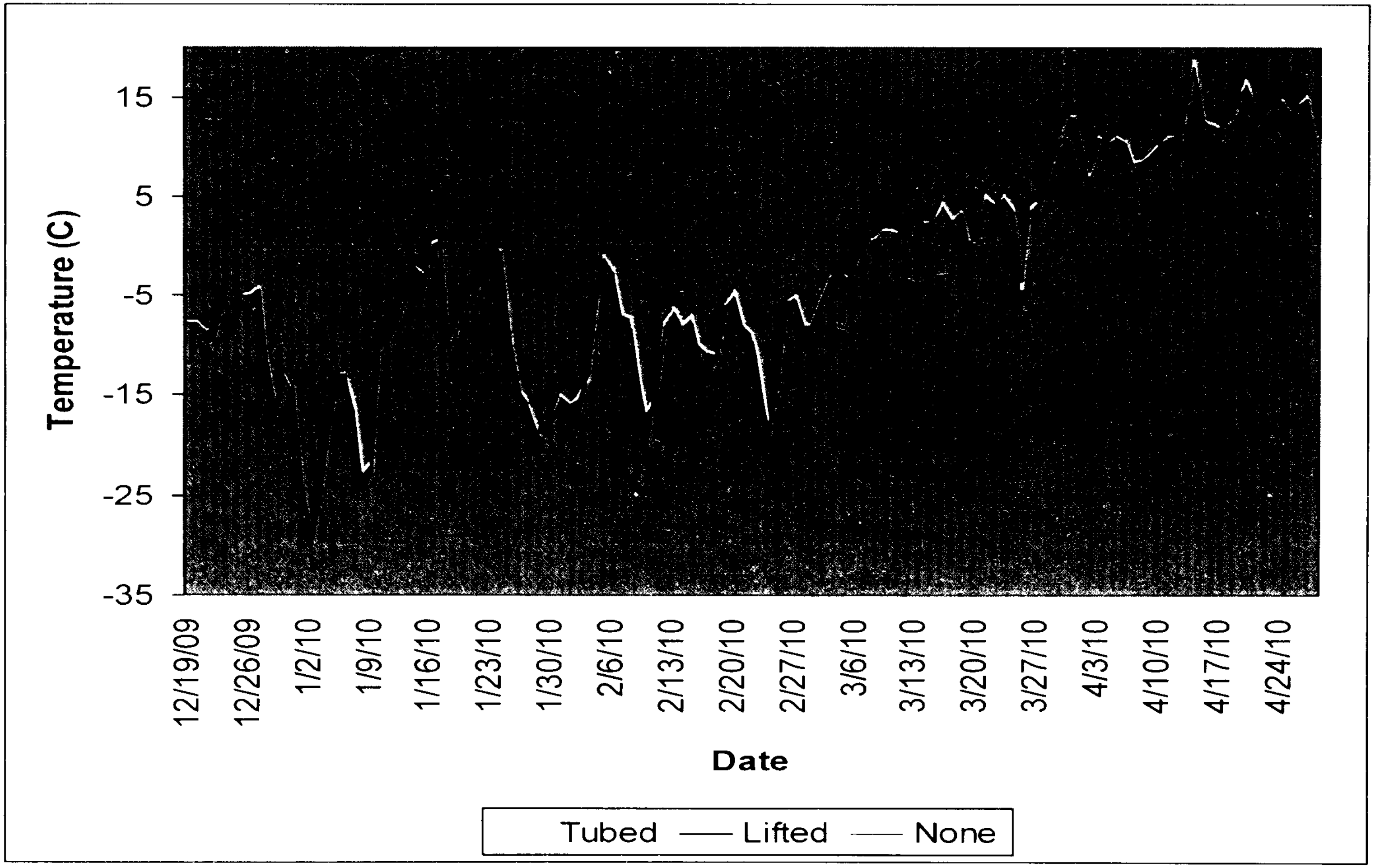

Fig. 4. Effect of grow tube treatment on daily average temperature in 2009 and 2010.

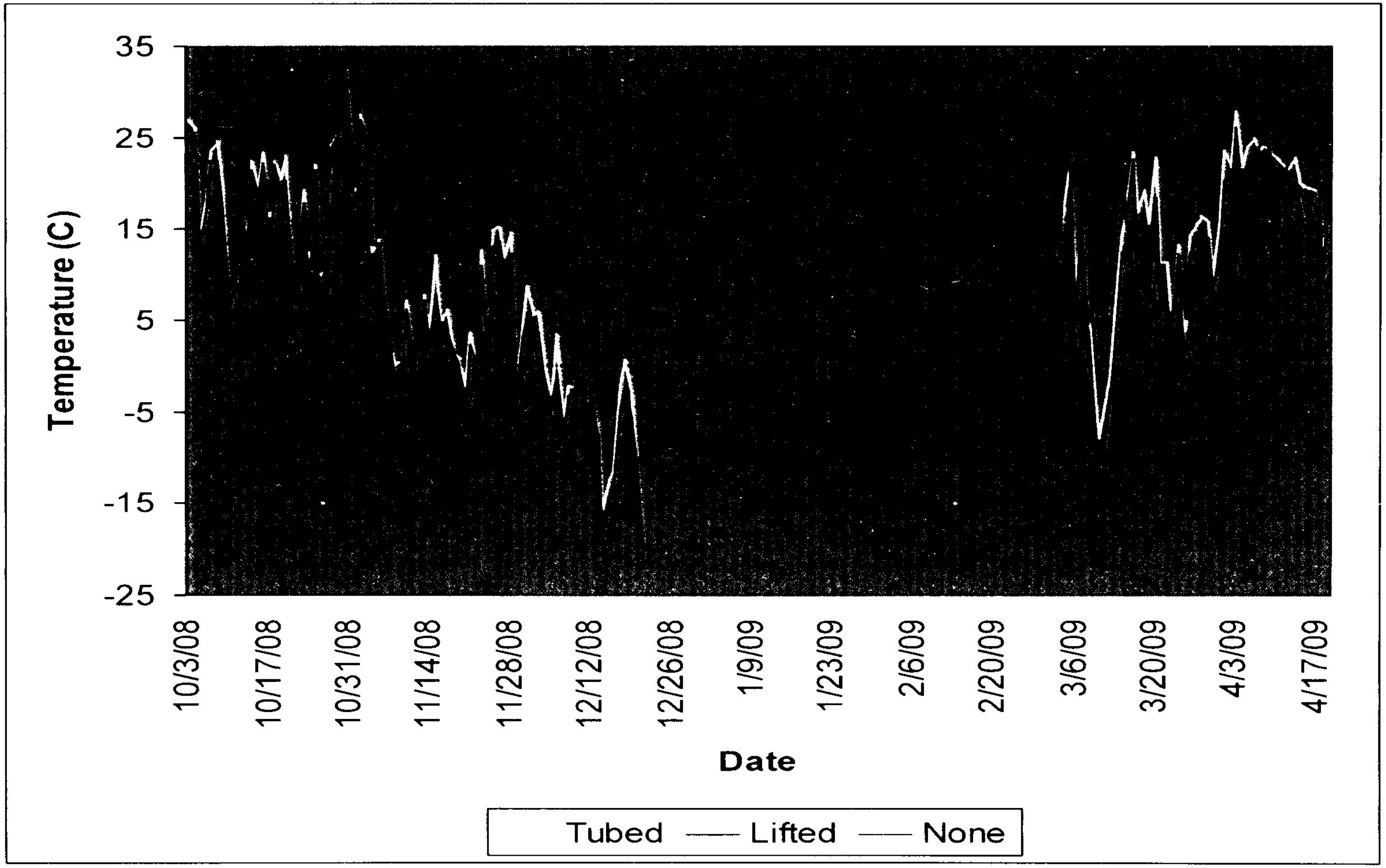

Fig. 5. Effect of grow tube treatment on daily maximum temperature in 2008 and 2009.

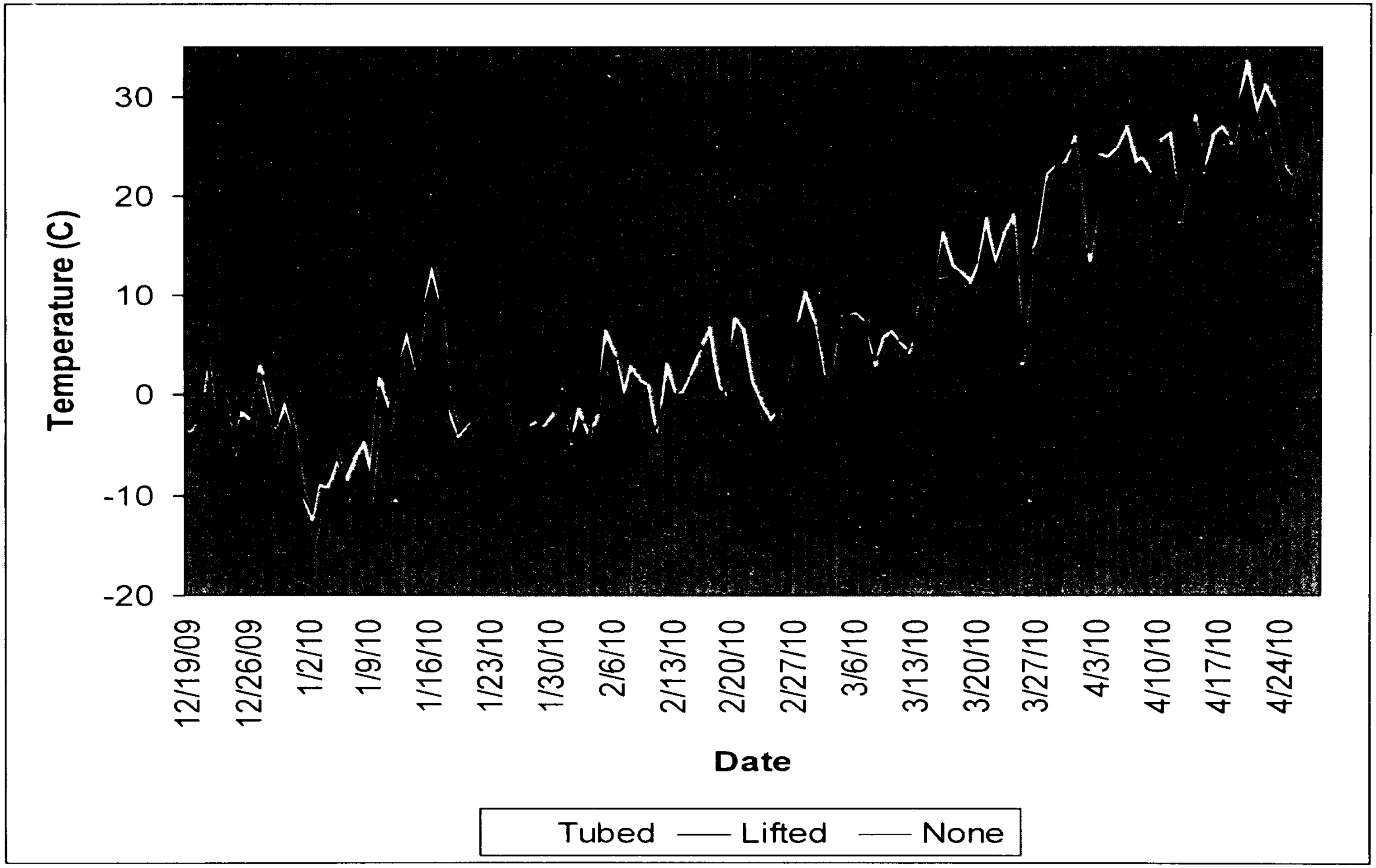

Fig. 6. Effect of grow tube treatment on daily maximum temperature in 2009 and 2010.

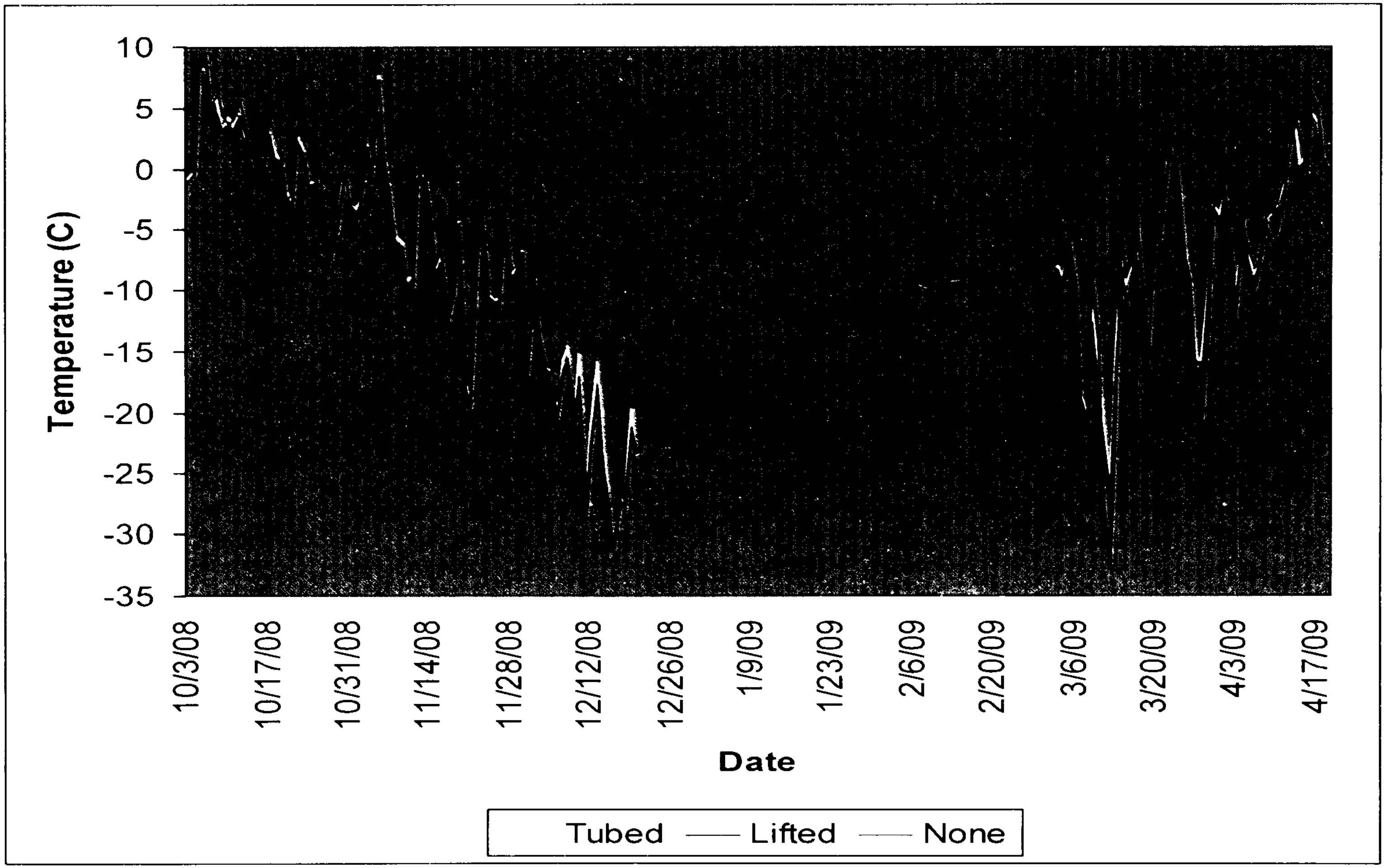

Fig. 7. Effect of grow tube treatment on daily minimum temperature in 2008 and 2009.

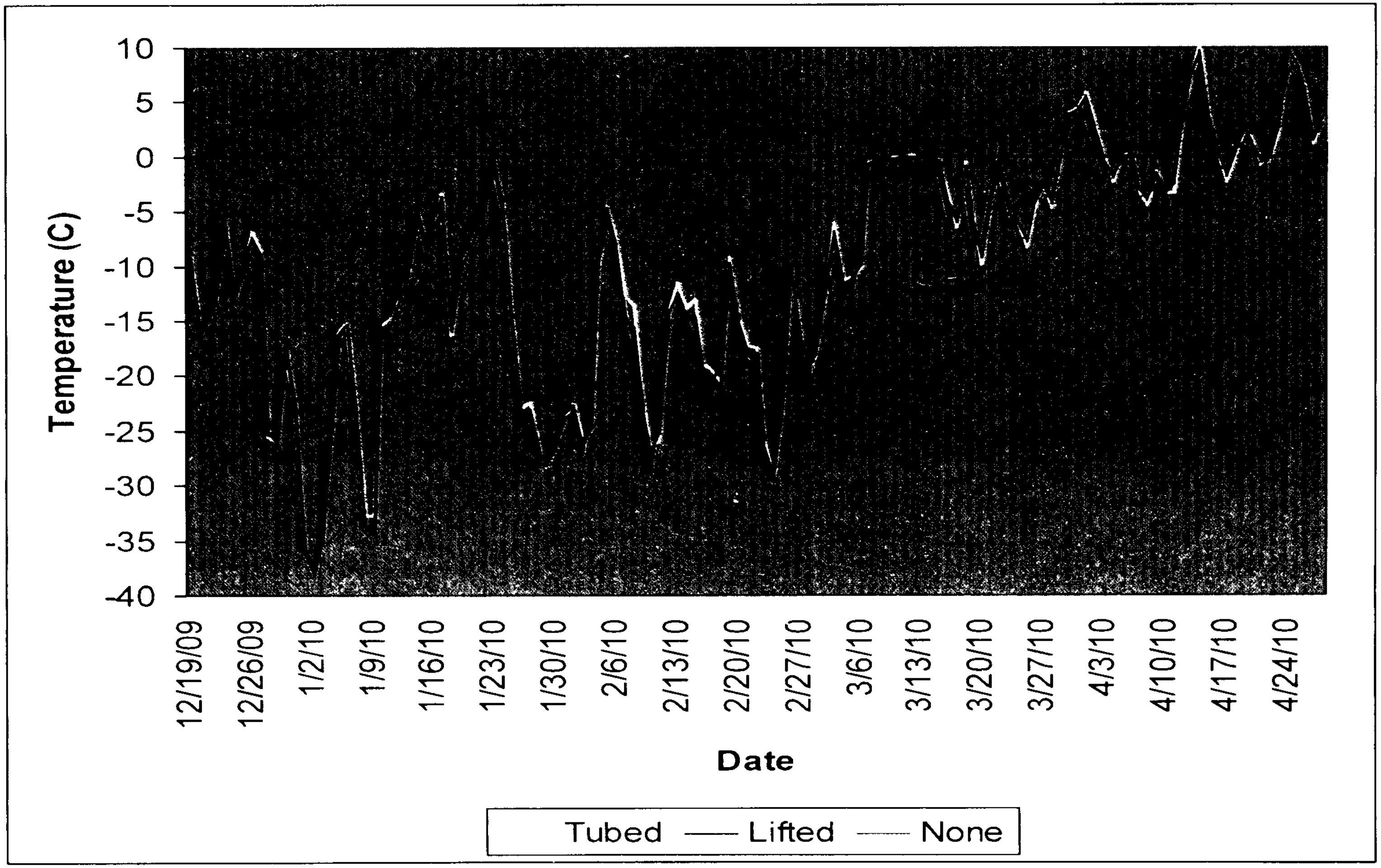

Fig. 8. Effect of grow tube treatment on daily minimum temperature in 2009 and 2010.

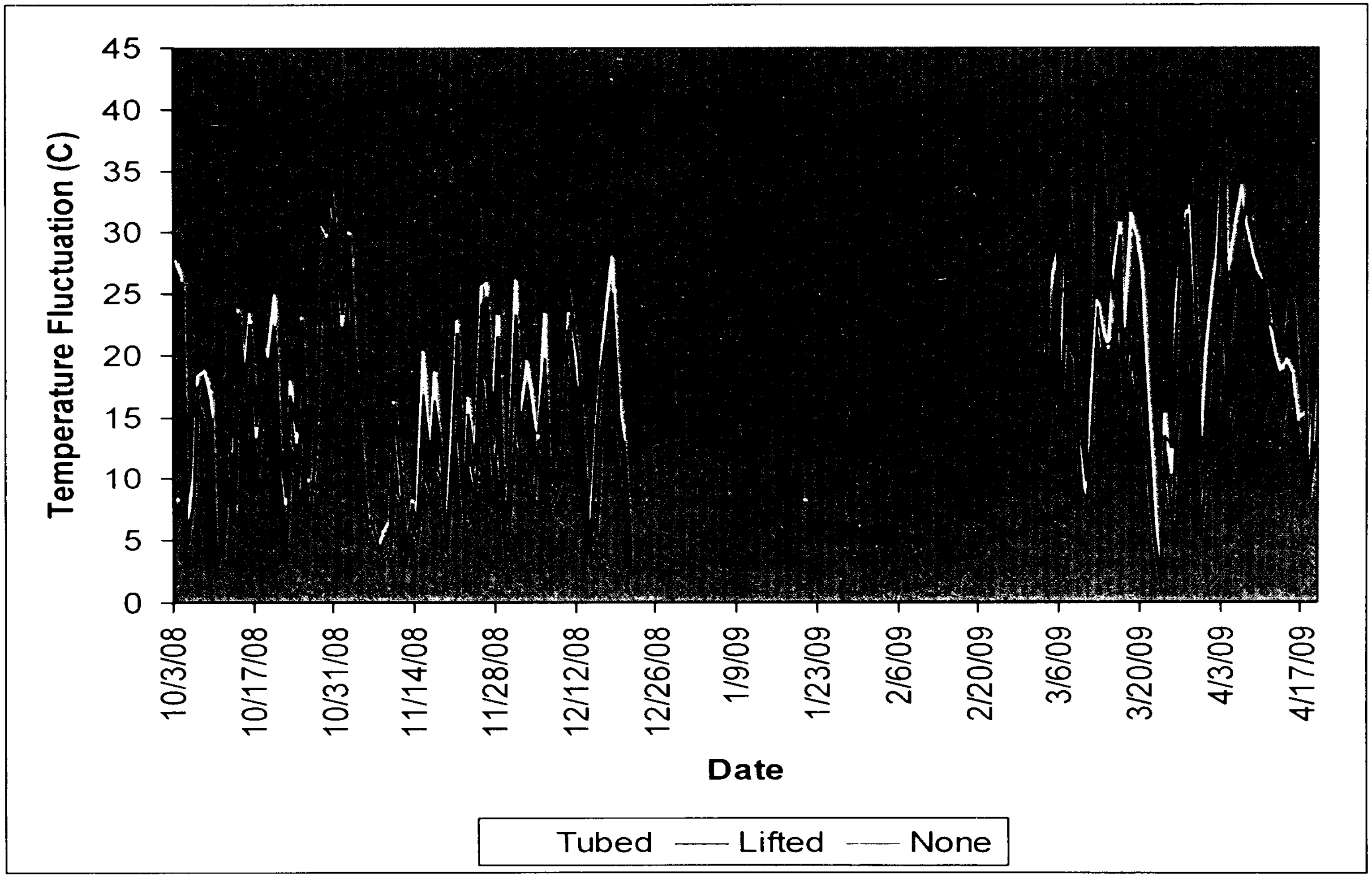

Fig. 9. Effect of grow tube treatment on daily temperature fluctuation in 2008 and 2009.

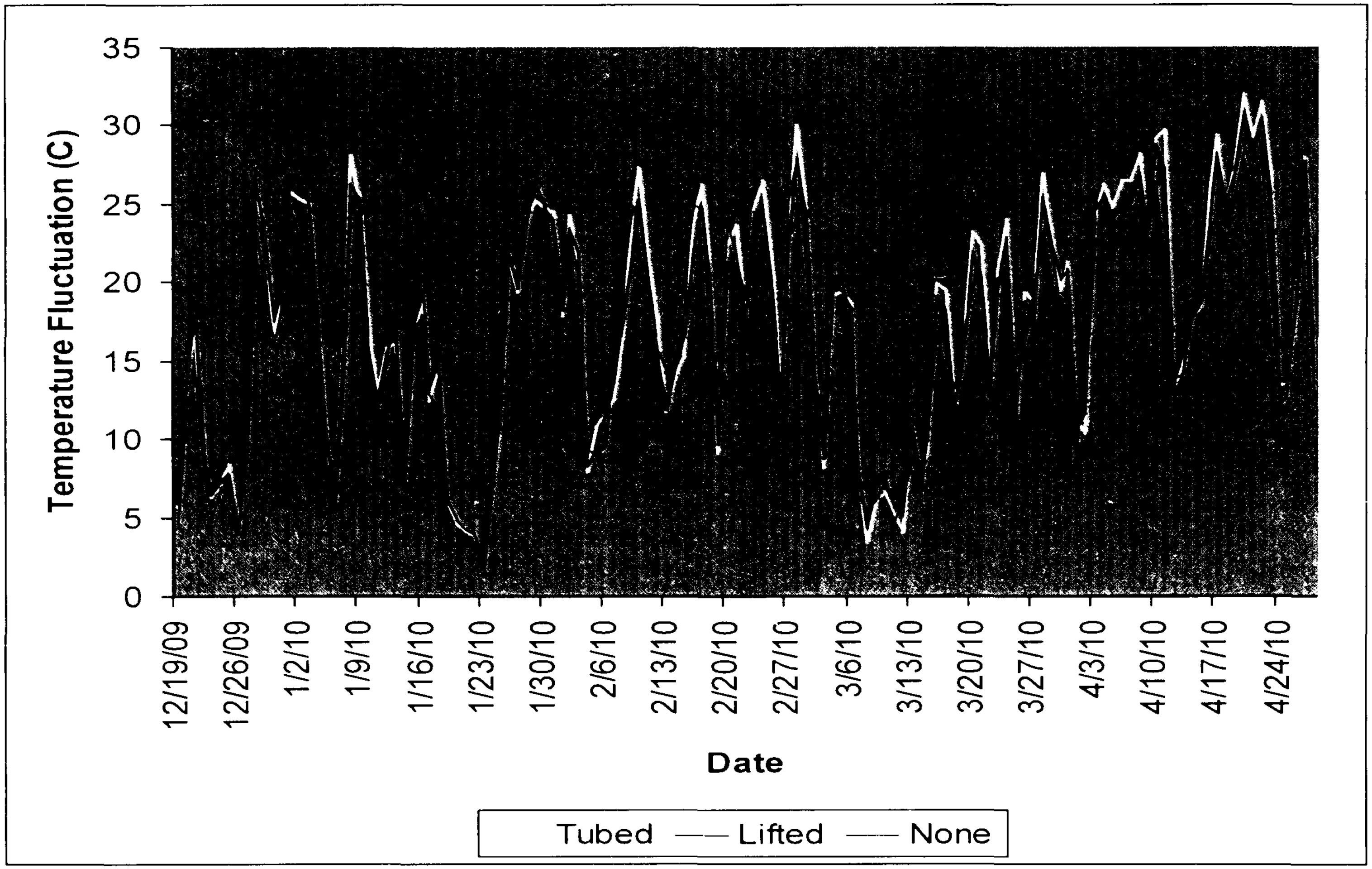

Fig. 10. Effect of grow tube treatment on daily temperature fluctuation in 2009 and 2010.

Table 9. Effects of treatments on average root diameter in 2009 combined over two locations.

Grow tube	Average root diameter
	------- mm -------
None	0.417
Fall removal	0.434
Full year	0.434
Fall lift	0.423
LSD (0.05)	ns[z]
Pruning level	------- mm -------
None	0.459
Pruned	0.420
LSD (0.05)	ns

[z] ns = not significant.

When hardiness was evaluated through the comparison of total nodes prior to the initiation of spring growth and the number of viable buds after initiation of spring growth, no significant differences were seen among grow tube treatments (Table 12). When pruning level was evaluated, plants that were not pruned had more total nodes prior to initiation of growth in the spring. This, however, did not lead to an increase in the total

Table 10. Effect of grow tubes and pruning level on bud break date in 2010.

Grow tube	Absaraka	Glyndon
	------- Julian days -------	
None	138.3	139.6
Fall removal	136.1	140.0
Full year	140.6	140.5
Full lift	141.3	140.2
LSD (0.05)	ns[z]	ns
Pruning level		
None	134.0	140.1
Pruned	138.2	140.1
LSD (0.05)	ns	ns

[z] ns = not significant

Table 11. Effect of grow tubes and pruning level on plant survival across two sites in the winters of 2009 and 2010.

Grow tube	Surviving plants
	----- no. -----
None	3.8
Fall removal	3.7
Full year	3.5
Fall lift	3.3
LSD (0.05)	ns[z]
Pruning level	----- no. -----
None	3.5
Pruned	3.6
LSD (0.05)	ns

[z] ns = not significant

number of viable nodes after the initiation of growth. This led to a significant decrease in percent node survival in non-pruned vines.

When vine height was evaluated, a significant increase in height was seen in tubed vines over vines that were not tubed in the summer of 2009 (Table 13). After the re-

Table 12. Effect of grow tube treatment and pruning level on number of total nodes, number of total viable nodes, and node survival averaged over locations.

	Total nodes	Total viable nodes	node survival
Grow tube treatment	------- no. per plant -----	------- no. per plant ------	------- % -------
None	48.6	4.9	11.7
Fall removal	44.0	2.9	7.2
Full year	47.5	2.1	5.2
Full year with fall lift	47.4	2.1	4.9
LSD (0.05)	ns[y]	ns	ns
	------ no. per plant ------	------- no. per plant --------	-------- % --------
Pruning level			
None	55.7 a[z]	3.0	6.1 b
Pruned	38.1 b	2.9	8.4 a
LSD (0.05)	8.7	ns	2.0

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

initiation of growth in the spring of 2010, no statistical differences were observed among grow tube treatments for height of the tallest viable node. An interaction was found between grow tube use and pruning level for height retention (Table 14).

Table 13. Effect of grow tube treatment and pruning level on first year height and height of the tallest viable node.

Grow tube	Fall height		Height of tallest viable node
	-------- cm --------		-------- cm --------
None	67.8	b[z]	21.6
Fall removal	135.3	a	19.1
Full year	141.6	a	12.8
Full year with fall lift	139.4	a	14.3
Pruning level	-------- cm --------		-------- cm --------
None	120.4		16.8
Pruned	121.6		17.0

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

Table 14. Effect of grow tube treatment and pruning level interaction on retained vine height[y] combined across locations.

Interaction			
Grow tube treatment	Pruning level	Retained height	
		----- % -----	
None	None	35.1	a[z]
None	Pruned	31.5	a
Fall removal	None	12.5	bc
Fall removal	Pruned	16.7	b
Full Year	None	9.4	c
Full Year	Pruned	8.9	c
Fall Lift	None	10.1	c
Fall Lift	Pruned	10.8	c

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] Evaluated using an arcsine transformation.

Discussion

Stem Growth

In 2009, the increase in number of leaves and shoots in vines that were not pruned compared to vines that were pruned was thought to be due to the increased number of buds retained. This increased number of buds lead to an increase in the number growing points. The overall increase in estimated total leaf area was thought to have occurred due to the increased number of leaves. Single leaf area had little contribution to the differences in total leaf area. This similarity in single leaf area was unexpected because fewer buds were retained in pruned treatments. Therefore, it was anticipated that growth would be concentrated resulting in increased leaf size. The lack of differences among grow tube treatments in 2009 was unexpected. It was thought that increased amounts of growth in vines having grow tubes would have lead to an increase in leaf area measurements. In this experiment, this was not the case.

In 2010, leaf area parameters were affected differently from what was observed in 2009. First, an interaction between pruning level and the use of grow tubes was found in single leaf area. Vines tended to remain more constant in single leaf area with the changing of grow tube treatments when pruned compared to vines which were not pruned. This possibly suggests that when vines are not pruned, they are more sensitive to environmental changes brought about by the grow tubes. Also, in cases where either grow tubes are not used or grow tubes are applied for the full season; it made little difference whether or not the vines were pruned in terms of single leaf area. When grow tubes were applied to vines then removed in the fall, increased single leaf area was found when vines were also pruned.

Lastly, when grow tubes were applied for the full year and were lifted in the fall, increased single leaf area was found in vines that were also not pruned.

In all other measures of leaf area parameters, no interactions were observed, but changes from what was found in 2009 were detected in 2010. Even though no differences occurred in leaf number, stem number, and total estimated leaf area in 2009 among tubed treatments, all of these measurements showed separation between treatments in 2010. In all three measurements vines that were not tubed had increases over tubed treatments. This suggests improved overall vine growth in the second season when grow tubes are not used at transplanting.

Though differences in number of leaves, number of shoots, and total estimated leaf area occurred in 2009 when pruning level was evaluated, no differences were found in any stem growth test in 2010. Since similar stem growth values occurred in the second growing season, pruning at transplanting provided no long-term benefit or hindrance in actual leaf area.

When plant height was evaluated in the fall of 2009, statistical separation occurred in the grow tube treatments. Heights of vines utilizing grow tubes where the tubes were retained for the full year, retained for the full year and lifted in the fall, or removed in the fall were not different from one another, but were all greater than vines that did not receive tubes after the first growing season. It was found that the greatest amount of growth was in vines where tubes were utilized during the first growing season. The increased growth in tubed vines was anticipated because these treatments benefited from the growth aiding effects of the grow tubes.

In the pruning level treatments, no differences were found between treatments in fall shoot height. This result was somewhat surprising, since fewer buds were present in the pruned treatments. It was anticipated that increased amounts of stem growth would have been seen in these vines. Growth was most likely reduced in the vines that were not pruned with the knowledge that heights were reduced in pruned vines at the beginning of the season. This being said, though increased growth was likely in the pruned vines it was not enough to overcome the reduction in plant height due to pruning.

Winter Temperature

The average daily temperatures in both winters (2008-2009 and 2009-2010) tended to be consistent across treatments. The presence or absence of a grow tube when either lifted or not lifted did not tend to alter the average temperature in most days. This suggests that all treatments showed similar general temperature patterns. However, increasing differences were seen in the 2009-2010 season with the approach of spring. As temperatures began to increase, more separation between average temperature trends were seen. The separation occurred by an increase in both tubed (lifted and not lifted) and the non-tubed treatments. This may suggest that under warmer temperatures (>0°C), overall increases in average temperature may be seen within grow tubes.

When maximum daily temperatures were investigated during the winter of 2008-2009, overall increases in maximum temperature trends were found in the two treatments where vines had grow tubes. This suggests a trend toward higher daily high temperatures under the influence of grow tubes. In the winter of 2009-2010, little separation in maximum temperature was seen in the colder months of December and January, but as daytime temperatures and day-length began to increase in February through April, the separation in maximum temperatures between the two grow tube treatments and treatment without grow tubes increased. This suggests that grow tubes alter the microclimate around the vine and that a larger fluctuation may occur during warmer periods. Therefore, bud death due to late fall and early spring frosts may be a concern when grow tubes are used. Less concern may be place on reductions in cold hardiness due to the use of grow tubes during the coldest months of the year, due to smaller differences between maximum temperature trends near vines that were tubed and vines that were not tubed. The increase in daily high temperature may also be responsible for the increased average temperature, since both had similar trends of increased separation during increasingly warmer conditions of the same time period.

To investigate any likelihood of a grow tubes ability to buffer or insulate the vine from low temperatures, the daily minimum temperatures were visually assessed for the tubed vines (lifted and not lifted), and vines without tubes. In the winter of 2008-2009, it appeared that relatively little deviation in daily minimum temperature occurred among treatments. During March through April, when large drops in minimum temperature occurred, vines which had lifted grow tubes tended to have much lower temperatures than all other treatments. Through speaking with F.A. Akyuz (Personal Communication, September 9, 2010), it was suggested that this phenomenon could be due to one or a combination of environmental factors, which included the early morning movements of cold air masses coupled with the insulating or shielding effects of the tube.

In the winter of 2009-2010, relatively small deviations were found between treatments in daily minimum temperature. For nearly the entire observed period, all treatments followed a similar pattern and had only minor separations from one another. It was noticed that in March and April of 2010 minimum temperatures tended to be mediated when no tube was present compared to vines that had tubes (whether lifted or not). On days of high minimum temperature, vines that were not tubed experienced slightly lower minimum temperatures. On days of low minimum temperature, slightly increased minimum temperatures were experienced. This suggests that the use of grow tubes may increase the variation of minimum temperature in spring months.

The daily temperature fluctuation was also monitored. In the two years (2008-2009 and 2009-2010) differing results were obtained. In the winter of 2008-2009, vines without tubes yielded lower daily temperature fluctuation than vines with grow tubes. In 2009-2010, vines without tubes had lower amounts of daily temperature fluctuation in the warmer spring months compared to all other vines, but higher amounts of daily temperature fluctuation during the colder winter months at times where temperatures were relatively stable. When the temperature data for the two years are viewed together, vines without grow tubes tended to have reduced levels of daily temperature fluctuation. In certain instances where there are fewer deviations in daily temperature, such as low maximum temperature or low solar radiation days, the grow tubes may have a regulatory effect on the vines. This effect may buffer the near vine air mass from large temperature swings.

Root Growth

No statistical differences were found among treatments for measurements of root growth. It is thought that the test contained excessive variation due to random chance of contacting root masses, which resulted in large variations within treatments. Though differences did not exist between treatments, some trends were found. In both locations, pruned vines tended to have increased amounts of root length, surface area, volume, and number of root tips over vines that were not pruned. Alternatively, average root diameter tended to be higher in vines that were not pruned. Increases in root surface area, root volume, and root fragment length, with an overall reduction in root diameter may indicate an increase in the production of small fibrous roots in pruned vines and fewer, larger roots in those that were not pruned.

Phenology

To evaluate treatment effects on vine susceptibility to frost damage phenological data was evaluated. For either location in both grow tube treatment and pruning level, no differences were detected. Therefore, none of the treatments are more or less susceptible to spring frost damage due to earlier bud break time. This does not, however, rule out the possibility that a grow tube could in some way shield initiated vines from frost.

Winter Hardiness

To determine the effects of treatments on winter hardiness seven factors were evaluated. First, no significant differences occurred between treatments for overall plant survival.

Secondly, the total number of nodes present per plant from the previous season's growth was evaluated. No differences were found among grow tube treatments. This indicates that neither the presence nor the absence of grow tubes influenced overall node production in the 2009 season. However, vines that were not pruned had greater node production in the 2009 season compared to vines that were pruned. This was expected due to the creation of more stems from the increased amount of retained buds at transplanting on vines that were not pruned compared to vines that were pruned.

There were no significant differences for total viable bud count. This indicates that the presence or absence of a grow tube did not alter the total number of nodes able to actively grow in the second season. It also indicates that pruning level had no effect on the total number of buds retained for growth in the second season. In both locations, vines which were never tubed tended to have more viable buds.

Another set of data investigated was the total height growth in the previous season. As mentioned previously, less growth was seen in vines that were not tubed when compared to all other treatments. This indicates that grow tubes do increase vertical growth in vines during the first season. However, the gains realized in the first season were not retained after winter, as there were no differences in height to the tallest viable node for either the grow tube or pruning level factors. This indicates that all treatments were equal in their ability to retain growth through the winter regardless of the vine height accumulated during the previous growing season.

An interaction between grow tube and pruning levels indicated that vines without grow tubes, either pruned or not pruned, had the greatest percentage of retained vine height compared to all other treatments. This was probably due to their reduced amount of growth in the previous season, being that no differences were detected in height to the tallest viable bud, but significant differences were found among fall shoot heights. Within vine where grow tubes were removed in the fall, no differences were observed between vines that were pruned or not pruned. These vines were lower in percentage of retained height than vines that were never tubed and were either pruned or not pruned. When grow tubes were removed in the fall on pruned vines, height retention was greater than all vines that had grow tubes that were retained for the full season, either lifted or not lifted, which were either pruned or not pruned. Vines where tubes were removed in the fall and were not pruned were similar to all vines that had grow tubes that were retained for the full season, either lifted or not lifted, which were either pruned or not pruned.

Overall, winter tended to be an equalizing factor. Though a number of node differences occurred in the pruning level factor and height differences occurred in the grow tube factor prior to winter, all significant differences were erased from these areas after winter, canceling all effects gained in the previous growing season. It is important to note the winter which was evaluated was exceptionally difficult, thus results may have been different in more typical years.

Conclusions

No difference existed among treatments after one full year's time based on plant growth initiation height and number of viable buds. The second year data of above ground growth, following removal of all grow tubes, showed that vines that had not been tubed during the first season had greater growth after the equalizing effects of winter. This suggests that overall vine health was increased when tubes were not used. For this reason, it is recommend that growers refrain from utilizing grow tubes in North Dakota when transplanting dormant two-year old vines to allow for better recovery and success the following spring. If grow tubes are utilized they should be removed at an earlier stage than was evaluated in this experiment.

As for pruning level, increased leaf area was seen in the first season of growth when vines were not pruned. This was caused by increased leaf and stem numbers due to increased numbers of retained buds. This advantage was eliminated in the second season of growth where all treatments were similar for all tests. For this reason, it is recommend that growers eliminate the additional expense of pruning at transplanting unless a pruned vine would assist with weed management operations.

Overall, an establishment system in which vines are not tubed and pruning at transplanting is done in accordance with ease of production for the grower is recommended. Further experimentation should be done to confirm this data. The winter conditions in this experiment were determined to be atypically harsh. Further experimentation would give a better perspective of effects across a broader set of environmental conditions including more typical situations.

CHAPTER II.

EFFECTS OF WEED CONTROL METHOD ON GRAPEVINE ESTABLISHMENT IN THE UPPER MIDWEST

Introduction

For success in grapevine establishment, weed control must be effectively implemented without harming the grapevine. Weedy plants can reduce grapevine vigor through competition for nutrients, space, and water. Successful control of weedy plants within a vineyard can result in the difference between economic profit and loss.

The use of mulch to control weeds has been common in ornamental horticulture and production orchard settings. Mulch has also been considered for use in vineyard weed control in the eastern United States, but its effectiveness is currently unknown in the extreme climatic conditions of the upper Midwest (Skinkis, 2011). Beyond weed control, mulches influence the microclimate surrounding the desired plants. Soil water conservation properties been seen, as well as alterations in soil temperatures due to mulch use. The effects of these altered environmental conditions may have production consequences.

Grapevines are generally adapted to more southerly latitudes (Arroya-Garcia et al., 2006). In northern climates grapevines may display unreliable hardiness during atypical winter weather conditions. Increases in hardiness and shortened non-productive periods must be achieved to realize the full potential of northern vineyards. Mulches, and their soil modifying properties, may influence many physiological and phenological functions of plants through environment modification (Downer and Faber, 2003; Kohnke and Werkhoven, 1963). However, the response of grapevines grown in northern regions to alterations to physiological and phenological processes is unclear.

Materials and Methods

Trial Locations

For the assessment of weed management practices on the establishment of grapevines in cold climates, an experimental trial was established near Kindred, ND at the Ekre North Dakota agricultural research station July 25, 2007. The trial was planted on Matador-Delamere-Wyndmere fine sandy loam (National Cooperative Soil Survey, 1999). This trial was arranged as a spit-plot design with main-plots consisting of four weed control methods and four cultivars assigned to the sub-plots with three replications. All main-plot treatments were randomized within replicates, and all sub-plot treatments were randomized separately within each main-plot.

The trial was arranged in a typical trellised vineyard fashion with rows in a north to south orientation spaced 3.1 m (10 ft.) apart containing vines spaced 2.4 m (8 ft.) apart. Each experimental unit consisted of two adjacent vines within a row or a sub-plot. The treatments utilized in the trial are listed in Table 15.

The herbicide treatments were applied on May 1, 2008 and May, 27 2009 with a combination of oryzalin 2.2 kg ai/ha (Surflan 4.7 l/ha), flumioxazin 71.5 g ai/ha (Chateau

WDG 140.1 g/ha), and glyphosate 867.2 g ai/ha (Roundup Weather Max 1.6 l/ha) as a single application. The straw and woodchip mulch were applied the same day as the chemical application during the first season. Additional mulch was added in the spring of the subsequent year at the same time as the chemical application. The landscape fabric treatment was applied at the same time as all other treatments in the first season. The fabric was reinforced with a heavier woven fabric during the first season due to its inability to eliminate light penetration and thus allowed vegetative growth under the fabric. After this alteration no changes were made to this treatment.

Table 15. Treatments utilized in the Kindred, ND, trial weed control trial.

Main-plot weed control treatment	Sub-plot variety treatment
Herbicide	St. Croix
Herbicide	DM 8521-1
Herbicide	MN 1200
Herbicide	MN 1131
Landscape Fabric	St. Croix
Landscape Fabric	DM 8521-1
Landscape Fabric	MN 1200
Landscape Fabric	MN 1131
Straw	St. Croix
Straw	DM 8521-1
Straw	MN 1200
Straw	MN 1131
Woodchip	St. Croix
Woodchip	DM 8521-1
Woodchip	MN 1200
Woodchip	MN 1131

The sub-plot treatments involved four different grapevine cultivars. The cultivars used were DM 8521-1, MN 1200, MN 1131, and St. Croix. These cultivars were chosen due to their perceived variation in cold hardiness and potential use in North Dakota for wine grape production.

In all treatments, perennial weeds were controlled by manual removal and spot application of glyphosate 867.2 g ai/ha (Roundup Weather Max 1.6 l/ha). The row middles were maintained as bare ground with a combination of tillage and spot applications of glyphosate 867.2 g ai/ha (Roundup Weather Max 1.6 l/ha).

Annual Weed Control

Annual weed control was evaluated two times per year for two years. Weed control was quantified as percent control by visual inspection compared to the weed presence in the plot margins. Percentages were averaged within variety sub-plots where 0 = no control and 100 = complete death. In 2008, weed control was evaluated on July 7 and again on September 22. In 2009, weed control was evaluated on July 13 and again on September 14.

Plant Growth

Plant growth was evaluated through measurements on plant height, stem number, dormant pruning weight, and green pruning weight.

Plant height for each year was measured in the period after the cessation of growth. Each plant was measured within the variety sub-plot and the average was utilized as a single value for each experimental unit.

Stem number was equivalent to the number of trunks from the base or near the base area of the vine. Stem number represented the average number of stems averaged across vines within each sub-plot. Data for this measurement was taken in the period after cessation of growth in the fall and before the continuance of growth or pruning in the spring.

Dormant pruning weight was determined as the total fresh weight in grams of dormant wood material removed from each vine during dormant season pruning. In the spring of 2009 and 2010, all vines were pruned in a similar manner under the goals of removal of dead plant material, establishment of the trunk, reduction in the number of trunks, removal of undesirable lateral branching, and establishment of cordons.

Green pruning weight was measured as the total weight of plant material removed from each vine during the summer growing months to partially determine vine growth. All vines were treated similarly in the utilization of green pruning under the goals of reducing the number of trunks per vine, promoting upward growth, and removal of undesirable lateral branches. Data was collected each time green pruning was implemented. Individual pruning dates were evaluated separately. Weights were obtained for each vine then averaged within sub-plots to generate a single value for each experimental unit.

Phenology

Phenology was monitored through the visual determination of vegetative bud break. Vegetative bud break data was evaluated by quantification of the number of days prior to when plant buds exposed green vegetation. The values in this study were expressed as Julian days. Each vine was evaluated separately then averaged within sub-plots to obtain a single value for each experimental unit.

Soil Conditions

Soil temperatures were measured using temperature thermisters (Decagon Devices Inc.) with periodic recording. Temperature thermisters were placed in the center of each main-plot approximately 15.24 cm (6 in.) deep in the soil. Data loggers were programmed to record soil temperature at one hour increments. Temperatures were recorded from July 8 through November 13 during the summers of 2008 and 2009. Soil temperatures were evaluated as average temperature within each month. Each month was evaluated separately.

Soil water content was also tracked through the growing season. Probes (Decagon Devices Inc.) were placed near the center of each main-plot approximately 15.24 cm (6 in.) deep in the soil to record soil water content on an hourly basis from July 8 through November 13, 2008 and 2009. Soil water content was then averaged within each month to obtain a single value to be analyzed. Each month was evaluated separately.

Winter Hardiness

Each plant within the trial was evaluated for its hardiness during the spring of 2010, after the onset of above freezing temperatures, but before bud break. This was accomplished by counting the number of viable buds in 50 bud samples from each plant. The results from two plants constituting an experimental unit were averaged and utilized for evaluations. Buds were selected to be representative of the whole plant containing buds from different stem sizes and positions on the plant. Buds were cut near their base on the stem. Those that were of green coloration were considered to be viable (Goffinet, 2004). Those that contained no green tissue were considered non-viable.

Statistical Analysis

All statistical evaluation was done using SAS 9.1 statistical software (SAS Circle P.O. Box 8000, Cary, NC 25712-8000). Weed control was evaluated as an RCBD with four treatments (main-plots evaluated averaged over sub-plots) and three replications. When percentages were evaluated, an arcsine transformation was applied to the dataset prior to statistical analysis.

Plant growth characteristics of: stem height, stem number, dormant pruning weight, green pruning weight, date of bud break, and bud counts were evaluated as RCBDs with split-plot arrangements consisting of four main-plots, four sub-plots and three replications.

For soil temperature and water content measurements, each month was evaluated separately as an RCBD with four treatments (main-plots averaged over sub-plots) and three replications. Data were combined where residual variances among years were homogeneous. Treatment means were separated, where appropriate, using Fisher's Protected LSD at the 0.05 level of significance.

Results

Annual Weed Control

Only two annual weed species, common lambsquarters (*Chenopodium album*) and yellow foxtail (*Setaria glauca.*), had consistent populations within the two growing seasons. Data was not combinable over 2008 and 2009 for early control of common lambsquarters, thus years were evaluated separately. Late control data was combinable over years for common lambsquarters. Yellow foxtail control data was combinable over 2008 and 2009 for early control, but not for late control. Late yellow foxtail control was evaluated separately for individual years.

For common lambsquarters, no significant differences in control were found among treatments in either year. All treatments were effective in controlling common lambsquarters. All treatments, both early and late in all years, had control greater than 80% (data not shown). Landscape fabric tended to have the most consistent common lambsquarters control with averages of 89.2% early and 90.4% late in the season.

There were no significant differences among treatments in early July for yellow foxtail control (data not shown). In the late evaluation of foxtail control for 2008, weed control was not significantly different among treatments despite a large range for average weed control with a low of 63% for the chemical treatment and a high of 90% for landscape fabric treatment (data not shown). However, in 2009 significant differences were found for late season yellow foxtail control (Table 16).

Plant Growth

Dormant pruning weights, green pruning weights, stem number, and stem length were evaluated. Dormant pruning was found to have heterogeneous residual variances across years, thus years were evaluated separately. For stem length and number data was found to be combinable, thus data were combined for 2008 and 2009. Variety had no

Table 16. Effects of weed control treatment on late yellow foxtail control[y] in 2009.

Weed control treatment	Yellow foxtail control
	--------------- % --------------
Fabric	90.4 a[z]
Chemical	49.2 c
Straw	82.9 b
Woodchip	85.4 ab

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] Evaluated using an arcsine transformation.

significant impact on dormant pruning weights in the spring of 2009 or 2010 (Table 17). No differences were found among weed control treatments.

Table 17. Effect of variety and weed control treatment on dormant pruning weight in 2009 and 2010.

Variety	2009	2010
	--------- g ---------	
St. Croix	132.3	219.7
DM 8521	189.0	296.5
MN 1131	111.0	544.0
MN 1200	120.5	385.1
LSD (0.05)	ns[z]	ns
Weed control treatment	--------- g ---------	
Fabric	153.6	349.6
Chemical	74.2	481.9
Straw	154.7	311.8
Woodchip	170.1	301.8
LSD (0.05)	ns	ns

[z] ns = not significant.

To better track the effects on vine growth, green pruning weights were also collected during the growing season in 2009 at two dates. No significant differences were found when the sub-plot varieties were compared at any date (Table 18). When weed control treatment main-plots were compared for their effect on within season green pruning weight, significant differences were seen on 10 July, 2009 but not on 4 August, 2009.

Table 18. Effect of variety and weed control treatment on green pruning weight for 10 July, 2009 and 4 Aug. 2009.

Variety	Date	
	10 July, 2009	4 Aug. 2009
	g	
St. Croix	297	158
DM 8521	510	236
MN 1131	500	315
MN 1200	470	223
LSD (0.05)	ns[y]	ns
Weed control treatment		
Fabric	390 b[z]	228
Chemical	816 a	274
Straw	323 b	266
Woodchip	249 b	164
LSD (0.05)	243	ns

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

No significant differences existed among any weed control treatment or variety for number of stems. The length of stem was also investigated to interpret the effects of weed control and variety on plant growth. No significant differences occurred among weed control treatments (Table 19). However, MN 1131 had significantly greater plant heights compared to either St. Croix or DM 8521. St. Croix was the slowest growing cultivar. MN 1200 did not differ from all other varieties within the study.

Table 19. Effect of variety and weed control treatment on stem length averaged across years.

Variety	Shoot length
	------------- cm ------------
St. Croix	204 b[z]
DM 8521	207 b
MN 1131	258 a
MN 1200	231 ab
LSD (0.05)	32
Weed control treatment	------------- cm ------------
Fabric	216
Chemical	258
Straw	229
Woodchip	199
LSD (0.05)	ns[y]

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

[y] ns = not significant.

Phenology

When data was combined over the two years, no statistical differences were found in either variety or weed control treatment in date of bud break (Table 20).

Soil Conditions

For soil conditions, data was combined over 2008 and 2009 when residual variances were found to be homogeneous. Soil water content data were combinable over years in all months (July, August, September, October, and November), while only July, August, October and November were combinable over years for soil temperature.

There were no significant differences among treatments for soil temperature or soil water content in July, September, October, and November (data not shown). A significant

Table 20. Effects of variety and weed control treatment on date of bud break date averaged across years.

Variety	Julian days
St. Croix	144
DM 8521	142
MN 1131	142
MN 1200	143
LSD (0.05)	ns[z]
Weed control treatment	
Fabric	143
Chemical	141
Straw	145
Woodchip	144
LSD (0.05)	ns

[z] ns = not significant.

year by weed control treatment interaction was detected for soil temperature in August (Table 21). No significant differences were found for soil water content among the weed control treatments in August (data not shown).

Table 21. Effect of year by weed control treatment interaction on August soil temperature.

Interaction			
Year	Treatment	C°	
2008	Fabric	22.8	b[z]
2009	Fabric	22.9	b
2008	Chemical	25.0	a
2009	Chemical	19.8	c
2008	Straw	20.4	c
2009	Straw	18.6	d
2008	Woodchip	22.2	b
2009	Woodchip	20.4	c
LSD (0.05)		1.2	

[z] Means followed by the same letter(s) are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

Overall, soil temperatures had similar trends throughout the growing season, with occasional rank changes by treatments (Fig. 11). Soil water content followed less defined trends than was seen in soil temperature possibly due to large number of missing data points during the months of October and November (Fig. 12).

Winter Hardiness

When bud survival was evaluated it was found that no significant differences existed between varieties or treatments in the spring of 2010 (Table 22).

Table 22. Effect of variety and weed control treatment on bud survival in 2010.

Variety	--- no. viable buds ---
St. Croix	5.000
DM 8521	0.774
MN 1131	0.792
MN 1200	3.030
LSD (0.05)	ns′
Weed control treatment	--- no. viable buds ---
Fabric	3.664
Chemical	0.667
Straw	3.500
Wood	1.764
LSD (0.05)	ns

′ns = not significant.

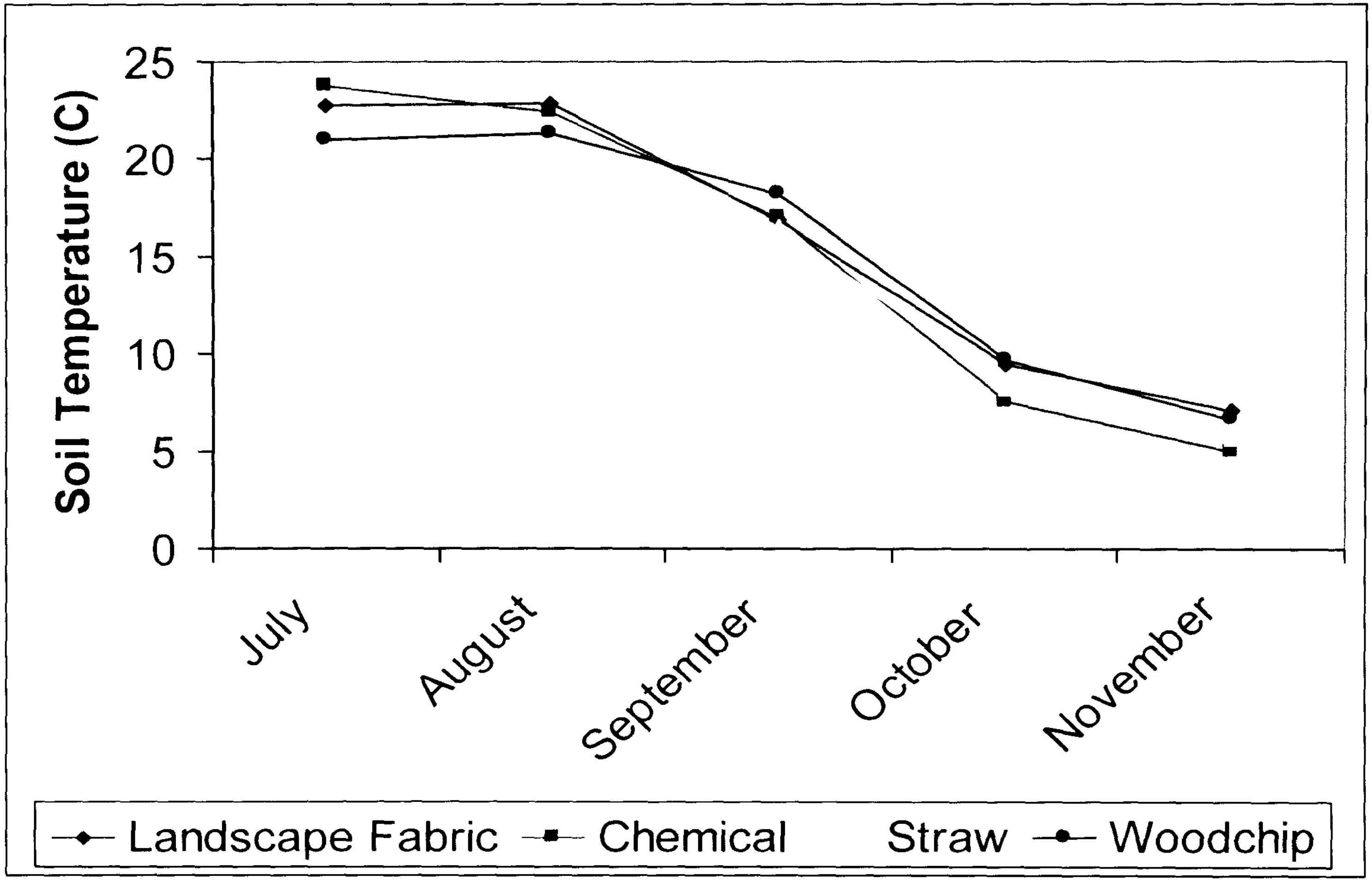

Fig. 11. Monthly soil temperature trends in Kindred, ND, averaged over all replications and years.

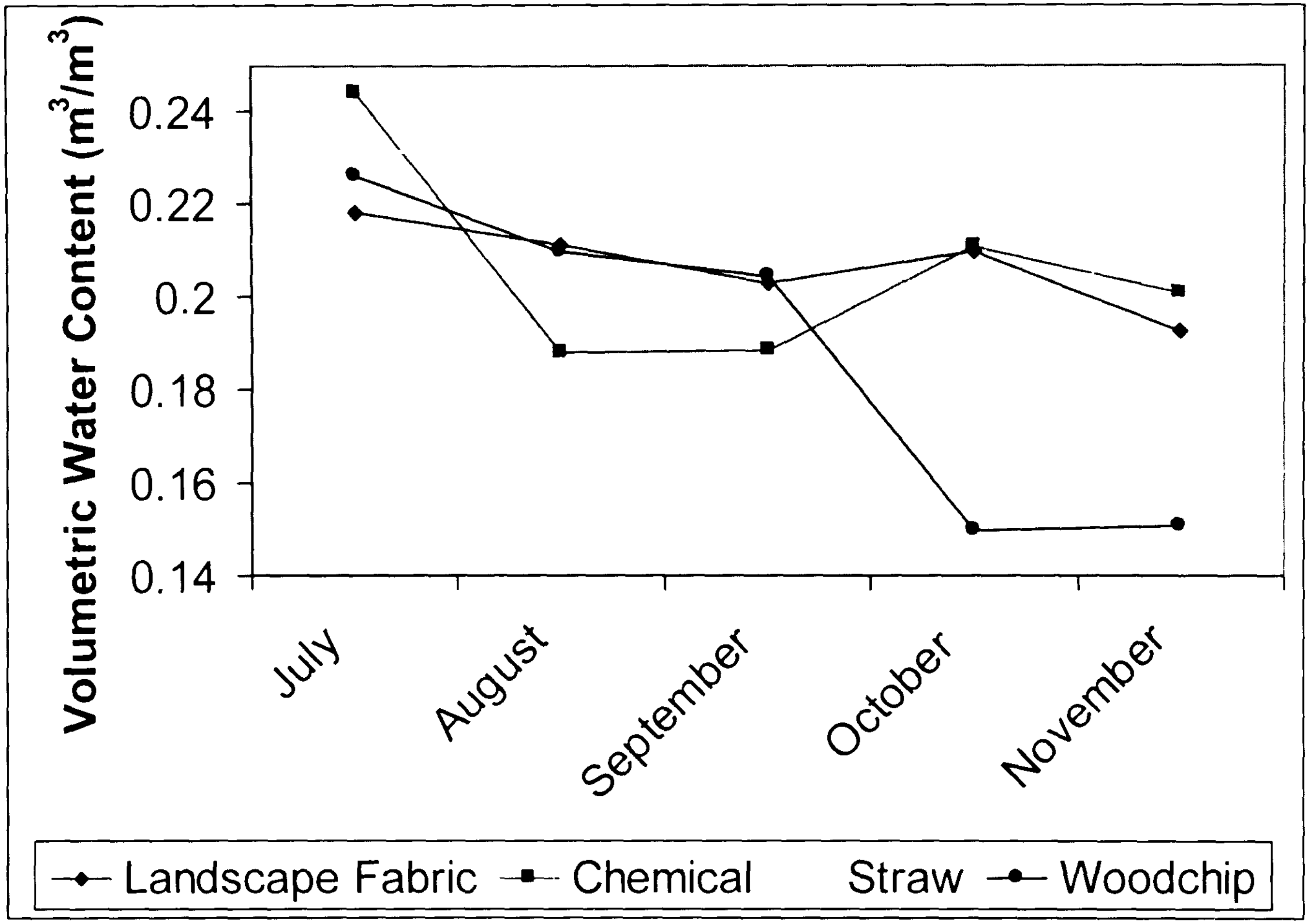

Fig. 12. Monthly soil volumetric water content trends in Kindred, ND, averaged over all replications and years.

Discussion

Annual Weed Control

The method of weed control was evaluated for early and late control of common lambsquarters and yellow foxtail. Since no differences were found for common lambsquarters control and control was overall very high (>87.0% in July and >82.9% in September), all treatments should be considered viable options. Mulch can be a viable alternative or aid to traditional chemical control within North Dakota.

For yellow foxtail, there were no differences among treatments in July. All treatment options provided acceptable early season yellow foxtail control, with all treatments providing greater than 89% control. In 2008, late season yellow foxtail control was not different among treatments despite a large range of weed control percentages with a low of 63% control in vines treated with herbicide to a high of 90% control in vines having landscape fabric. However, in 2009, differences were found among weed control treatments. Landscape fabric, woodchip mulch, and straw mulch provided greater late season yellow foxtail control compared to the chemical treatment in 2009. The difference in treatment effectiveness between years may have resulted from the numerically poorer yellow foxtail control in 2008 with the chemical treatment, which increased the soil seed bank compared to the other treatments. Another possibility would be reduction in herbicide effectiveness from environmental conditions, or an increase in mulch effectiveness due to the buildup of mulch materials. These results suggest that the residual effect of the herbicide combination was reduced late in the season for yellow foxtail and that better, long term control would be found through the use of mulches. The mulch treatments provided at least equivalent levels of yellow foxtail control to chemical control, with all mulch treatments in 2009 showing greater season long control than the chemical application.

In general, mulch alternatives for the control annual weeds appear to be at least equivalent to chemical control. Mulch may provide greater season long protection from annual weedy species, showing greater effectiveness late in 2009 on yellow foxtail. Since this was year dependent, much of the end of season effectiveness could be the result of the environmental conditions of the season. Also, other chemical control agents or a second application could allow for better long term control of annual weeds.

Plant Growth

All varieties appear to be similar in their growth pattern or at least in biomass production. Similar results were obtained in the comparison of weed control treatments. No significant differences were found among weed control treatments, suggesting that mulch alternatives have no impact on vine growth and performance during establishment when compared to a herbicide application.

Variety had no impact in this experiment in terms green pruning weights. This information, when combined with dormant pruning weights indicates that all varieties were similar in size, growth rate, and growth pattern.

When weed control treatments were compared for their effects on green pruning weight, differences were seen on July 10, 2009. The evaluation of green pruning weights indicated that plots that had herbicide applications had higher pruning weights when compared to any vines treated with mulch. This suggests increased levels of growth may have occurred in the spring and early summer of 2009 in herbicide treated vines when compared to all vines treated with mulch. However, on August 4, 2009 no significant differences were detected among weed control treatments in green pruning weight. This suggests that even though early growth may have been greater for plots treated with herbicides, this advantage was overcome with all vines being similar in growth after 25 days.

Nonetheless, if vine vigor is lower than acceptable, then the use of mulch may not be recommended. Fortunately, many northern climate cultivars are highly vigorous and the addition of mulch for weed control may also be a benefit in vigor reduction.

Stem production was not affected by the weed control measures applied, and all varieties were similar in their growth pattern. There were also no stem length differences due to weed control treatments. This was expected since weed control treatments did not differ for common lambsquarters or yellow foxtail control in most situations, thus weed competition influence on shoot growth should be similar.

Stem length differences did occur among grape varieties with MN 1131 vines growing taller than either St. Croix or DM 8521 vines. St. Croix and DM 8521 vines were similar in plant height and had the shortest stem length. The vine height for MN 1200 was similar to all other cultivars utilized within the study. Variety MN 1131 had more vigorous upright growth than St. Croix and DM 8521, but not MN 1200. This suggests that MN 1131 is a faster growing variety or benefited from less winter die back than the either St. Croix or DM 8521 in this study. Therefore, this variety maybe better suited for wine grape production in North Dakota.

Overall, conclusions can be made on both variety and weed control treatment in terms of plant growth in this study. Varieties had similar growth rates and patterns. The only test that resulted in growth differences among the varieties was shoot length, indicating that the growth and/or the winter hardiness of MN 1131 was greater than the either St. Croix or DM 8521 varieties. Based on this portion of evaluation, the use of either MN 1131 instead of St. Croix or DM 8521 is recommended in North Dakota. Most plant growth measurements: dormant pruning weight, total green pruning weight, stem number, and stem height, were not influenced by weed control treatments. Only green pruning weight in July was affected by weed control. Vines within the chemically controlled treatment had higher green pruning weights in July 2009. Keeping the soil bare with a chemical treatment may increase vine growth rates early in the season, but these differences last less than 30 days, suggesting that season long growth may not be affected.

Phenology

Bud break data indicate that all four varieties had similar bud break patterns and that weed control treatments had no effect on bud break date. This leads to the assumption that the tested vines utilizing differing weed control treatments are not at increased risk of bud loss caused by early spring freezing. This result was unexpected as previous research with mulches has shown reduced soil temperatures and increased soil water content compared to bare soil during the growing season (Chalker-Scott, 2007; Lizow and Pellett, 1983). Increased soil water and temperature should have reduced early season growth and prolonged bud break and deacclimation. Though no differences were found, trends suggest that chemically treated vines will break buds two to four days earlier than mulched vines.

Overall, it was observed that the order of treatments for earliest bud break were as follows: chemical, landscape fabric, woodchip, and then straw. These results were as expected due to the perceived ability of each treatment to absorb solar radiation and conserve soil water.

Soil Conditions

There was no difference in July soil temperatures among the weed control treatments. This result was unexpected considering the anticipated differences among treatments in soil water and reflectivity. In previous studies, differences in soil temperature between areas maintained with mulch and areas maintained as bare ground increased from spring to summer (Kohnke and Werkhoven, 1963). Thus, it is expected that soil temperature would not have increased if measured earlier in the season.

No differences in July soil water content among treatments suggests that the treatments had no apparent benefit or hindrance in either retaining or losing moisture. Therefore, differences in overall vine performance at this time would relate to cultivar differences. This result was also unexpected as Iles and Dosmann (1999) reported a 13% increase in soil moisture when mulched with woodchips above the 19% soil moisture found in their bare soil control. In the Iles and Dosmann experiment this difference was significant. In addition, they reported that all mulch treatments were significantly higher in moisture amounts than the bare soil control. However, Dennis Whitted (Personal Communication, December 29, 2010), Research Specialist assisting with the management of the Ekre Grassland Preserve where, indicated that this site is considered the Sheyenne river bottom with a reported high water table. This high water table may have altered the results of this experiment leading to high water content in all studied weed control measures regardless of their moisture conserving properties.

When soil temperature was evaluated in August an interaction was found between year and treatment. Much of the interaction appears to be in the use of chemical control across years. The highest soil temperatures were obtained using chemical control in 2008. However in 2009, the lowest overall temperatures were recorded for the chemical control. The cause of this variation between years in soil temperature when chemical control is utilized is thought to be either attributed to the lack of temperature mediating in bare soil compared to covered soil. In the experiment conducted it was seen that a greater reduction in soil temperature between the two years was found when chemical weed control was applied. When mulches were applied, reduced changes in soil temperature were seen. This is consistent with data obtained by the North Dakota Agricultural Weather Network (NDAWN) during August of 2008 and 2009 (North Dakota Agricultural Weather Network, 2000). For the two years, average air temperature, bare soil temperature, and turf covered soil temperature were recorded by a near by NDAWN station. The station recorded a daily average temperature for the month of August of 20.56°C in 2008 and 18.33°C in 2009. This shows a decrease in air temperature between the years of 2008 and 2009 for the month of August of 2.23°C. The average bare and turf covered soil temperatures for the month of August in 2008 were 23.89°C and 19.44°C respectively. Where as the bare and turf covered soil temperature for the month of August in 2009 were 20.56°C and 18.33°C. The turf covered soil temperature seemed to have lower differences between years as air temperature with a difference from 2008 to 2009 of 1.1°C. When bare soil is considered, the difference in temperature from 2008 to 2009 was 3.3°C. This displays an larger reductions in temperature from 2008 to 2009 in bare soil when compared to turf covered soil.

Mulch is often claimed to mediate soil and environmental conditions (Chalker-Scott, 2007). This could contribute to more consistent year-to-year soil temperatures, whereas chemically controlled vineyards may be more susceptible to varied environmental conditions. Small environmental differences between years may be expected due to decreases in straw and woodchips from 2008 to 2009. The second, and most likely explanation for the large deviation in soil temperatures in the chemically controlled treatments, is the lack of residual control of yellow foxtail by chemical treatments in 2009 when compared to 2008. Increased amounts of yellow foxtail may have altered solar radiation and resulted in decreased levels of solar heat warming the soil. Overall, the most consistent treatment for August soil temperature seemed to be landscape fabric with no difference between years.

When soil water content data were combined over 2008 and 2009 for August, no differences were found among the weed control treatments in this study. This was unexpected. It was thought that large differences would occur among treatments during warm times of the year due to the temperature mediating and water conservation properties of mulch (Chalker-Scott, 2007; Kohnke and Werkhoven, 1963).

In September through November, no significant differences were found among treatments for soil temperature or soil water content in 2008 or 2009. The lack of differences in the later months of the year could indicate that less effect is seen on soil temperature and water content with decreasing air temperatures.

Overall, weed control treatments did not differ greatly in their effect on soil water content during the growing season. When it came to soil temperature, differences in year by treatment interactions were only observed in August. The differences in this month can be attributed to the differences in temperature patterns between the two years, where larger decreases in bare soil temperatures were seen when compared to turf covered sites by the NDAWN weather station near Ekre, ND. In all other cases, buffering of heat and moisture were not found in the mulched treatments. If effects of the treatments are only observed at high temperatures of mid-summer, differences would be far removed from the critical acclimation and deacclimation times of spring and fall. This supports evidence that weed control treatments may not cause problems with phenology or with the acclimation processes.

When growing season trends were evaluated for soil water content it was found that the straw and landscape fabric treatments were consistent from month to month in value and in rank with straw having higher water content than landscape fabric. The chemical treatment tended to have less consistent values over months. These plots had high amounts of soil water content in July, but the soil water content decreased during the months of August and September, and then increased in October and November. The woodchip treatment tended to have stable levels of soil water content in July through September, but unexpected decreases in soil moisture were observed in October through November. These unexpected values in October and November may have been caused by the large number of missing data points in this region due to datalogger errors. This missing data may have influenced the overall averages of soil moisture within replications for months prior to statistical analysis.

When the overall trends of soil temperature were evaluated it was found that all treatments tended to follow a similar pattern for the season. All treatments had their highest soil temperatures during July and August with reductions in temperatures into October and November. Though all treatments followed similar trends, the rankings of treatments changed from month to month. Chemically treated plots tended to have the most change in soil temperature from month to month and experienced the greatest change in rank over the year compared to all other treatments. Chemically treated plots tended to have the warmest soils in July. By October, chemically treated plots tended to have the coolest soils and remained this way through November. This indicates that the chemical treated vines may be more susceptible to changes in environmental conditions. The woodchip mulch treatment also displayed an interesting trend. Woodchip treated plots tended to have relatively low July soil temperatures. However, by September, soil temperatures in the woodchip treatment were the highest of all weed control treatments. Woodchip treated plots had the highest soil temperature for the remainder of the year. This trend displays the anticipated moderating soil temperature effect of mulches. The mulch was successful in keeping soil temperatures cooler through the warmest parts of the year, but also tended to retain warmth late into the season. Straw mulch resulted in, for most of the evaluation period, at or near the lowest soil temperature. Landscape fabric tended to be intermediate compared to all other treatments in soil temperature for most of the season. Both straw and landscape fabric displayed evidence of soil temperature moderating effects, but not to the level found in the woodchip treatment.

Winter Hardiness

When bud survival was evaluated it was found that no differences existed among varieties or treatments in the spring of 2010. Based on visual evaluation of other vineyards and trails in the southern Red River Valley, the winter of 2009-2010 was more difficult than average. Most grapevines in south-eastern North Dakota received greater-than-average levels of dieback. This overall greater dieback may have reduced differences between varieties and treatments, making them more difficult to detect than on an average year. The lack of differences between treatments suggests that weed control options have little effect on winter hardiness as measured by bud survival.

Conclusions

Overall, it was found that all weed control treatments were similar in their abilities to control weeds, and in their effects on grapevines. Weed control was slightly improved by using the mulched treatments compared to chemical control in certain situations. Mulched plots had more consistent yellow foxtail control late in the season compared to the chemical treatment. However, the chemically controlled treatment had increased green pruning weights and mid-summer soil temperatures. The increase in green pruning weights is indicative of increased growth during the spring and early summer. No further evidence was found for season-long increases in growth within the chemical control treatment. The increased summer temperatures that were seen in the chemically controlled plots could have provided better opportunity for growth due to favorable conditions, but no such increase in growth was observed late in the season.

The evaluation of soil temperature and soil water content trends showed that mulched treatments tended to have more moderation of changes in soil temperature and soil water content. Alternatively, chemically treated plots tended to have high soil temperatures during warm months with relatively cool soil temperatures during cool months and more fluctuation in soil moisture from month to month. The moderation of soil temperature could be detrimental, due to possible reductions in acclimation in the fall, although winter injury or dieback was similar for all weed control treatments. Soil temperature moderation could also be advantageous in the delay of bud break in the spring, although no differences were found between treatments in bud break for this study.

Therefore, due to the perceived possible benefits and hindrances of using mulches to control weeds in grapevine establishment, the use of mulch or chemical based weed control options should be based on specific vineyard needs. Increases in green pruning weights were seen early in 2009, thus minute growth advantages may be seen with chemically treated vines. In cases where vineyard growth is adequate, mulch may be favored or added to supplement chemical based weed control. It was demonstrated that mulched vines had reduced green pruning weights, but also displayed more consistent late season yellow foxtail weed control. It is important to note that this experiment tested a limited number of years, thus deviations from results obtained in this experiment could be found in differing environmental situations. Further experimentation would help to confirm the findings of this experiment.

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APPENDIX

Table 1A. ANOVA for early common lambsquarters control in 2008.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	2	0.0090	0.37
Treatment	3	0.0044	0.18
Error	6	0.0242	-

Table 2A. ANOVA for early common lambsquarters control in 2009.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	2	0.0016	0.69
Treatment	3	0.0070	3.03
Error	6	0.0023	

Table 3A. ANOVA for early yellow foxtail control combined over years.

Source of variation	Degrees of freedom	Mean square	F-value
Year	1	0.0139	Not valid
Replication(Year)	4	0.0174	Not valid
Treatment (Trt)	3	0.0288	0.71
Year*TRT	3	0.0404	1.54
Error	12	0.0262	-

Table 4A. ANOVA for late common lambsquarters control combined over years.

Source of variation	Degrees of freedom	Mean square	F-value
Year	1	0.0001	Not valid
Replication(Year)	4	0.0073	Not valid
Treatment (Trt)	3	0.0150	3.00
Year*TRT	3	0.0050	1.45
Error	12	0.0035	-

Table 5A. ANOVA for late yellow foxtail control in 2008.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	2	0.0701	3.40
Treatment	3	0.0484	2.35
Error	6	0.0206	-

Table 6A. ANOVA for late yellow foxtail control in 2009.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	2	0.0033	1.88
Treatment	3	0.1371	76.99*
Error	6	0.0018	-

* Significant at the 0.05 probability level.

Table 7A. ANOVA for leaf area in Absaraka, ND in 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Replication	5	739060	0.83
Grow tube treatment (GT)	3	1807164	2.03
Pruning level (PL)	1	1842759	2.07
GT*PL	3	739856	0.83
Error	35	891468	-

Table 8A. ANOVA for leaf number in Absaraka, ND, in 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Replication	5	46.60	1.12
Grow tube treatment (GT)	3	7.70	0.19
Pruning level (PL)	1	1038.35	25.01**
GT*PL	3	71.41	1.72
Error	35	41.52	-

** Significant at the 0.01 probability level.

Table 9A. ANOVA for shoot number in Absaraka, ND, in 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Replication	5	1.771	1.68
Grow tube treatment (GT)	3	0.524	0.50
Pruning Level (PL)	1	71.094	67.30**
GT*PL	3	1.696	1.61
Error	35	1.056	-

** Significant at the 0.01 probability level.

Table 10A. ANOVA for estimated total leaf area in Absaraka, ND, in 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Replication	5	1961687042	0.55
Grow tube treatment (GT)	3	1946334824	0.54
Pruning level (PL)	1	27741863534	7.75**
GT*PL	3	3913783331	1.90
Error	35	3579406199	-

** Significant at the 0.01 probability level.

Table 11A. ANOVA for leaf area in Absaraka, ND, in 2010.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	5	9697307	5.55
Grow tube treatment (GT)	3	9311300	5.33*
Pruning level (PL)	1	267294	0.15
GT*PL	3	6379924	3.65*
Error	35	1747941	-

** Significant at the 0.05 probability level.

Table 12A. ANOVA for leaf number in Absaraka, ND, in 2010.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	5	4377	6.47**
Grow tube treatment (GT)	3	11667	17.26**
Pruning level (PL)	1	1149	1.70
GT*PL	3	399	0.59
Error	35	676	-

** Significant at the 0.01 probability level.

Table 13A. ANOVA for shoot number in Absaraka, ND, in 2010.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	5	0.2187	0.15
Grow tube treatment (GT)	3	31.9381	22.34**
Pruning level (PL)	1	5.1680	3.61
GT*PL	3	2.2332	1.56
Error	35	1.4313	-

** Significant at the 0.01 probability level.

Table 14A. ANOVA for estimated total leaf area in Absaraka, ND, in 2009.

Source of variation	Degrees of freedom	Mean square	F-value
Replication	5	7.52476E+11	8.94**
Grow tube treatment (GT)	3	9.59652E+11	11.41**
Pruning level (PL)	1	4564175479	0.05
GT*PL	3	65312501595	0.78
Error	35	84136585455	-

** Significant at the 0.01 probability level.

Table 15A. ANOVA for total fall shoot height Absaraka, ND, and Glyndon, MN, in 2009.

Source of variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not valid
Replication(Loc)	10	-	Not valid
Grow tube treatment (GT)	3	30379.1	34.17**
Pruning level (PL)	1	35.9	0.17
GT*PL	3	37.8	2.49
Loc*GT	3	889.1	4.95**
Loc*PL	1	212.8	1.19
Loc*GT*PL	3	15.2	0.08
Error	70	179.5	-

** Significant at the 0.01 probability level.

Table 16A. ANOVA for total root fragment length in Absaraka, ND, and Glyndon, MN, in 2009.

	Absaraka			Glyndon		
Sources of variation	Degrees of freedom	Mean square	F-value	Degrees of freedom	Mean square	F-value
Rep	5	14854	2.23	5	1005	1.01
Grow tube treatment (GT)	3	6502	0.98	3	871	0.87
Pruning level (PL)	1	622	0.09	1	259	0.26
GT*PL	3	9194	1.38	3	281	0.26
Error	34	6653	-	35	995	-

Table 17A. ANOVA for total root fragment surface area in Absaraka, ND, and Glyndon, MN, in 2009.

	Absaraka			Glyndon		
Sources of variation	Degrees of freedom	Mean square	F-value	Degrees of freedom	Mean square	F-value
Rep	5	795.5	1.99	5	50.8	1
Grow tube treatment (GT)	3	355.9	0.89	3	17.4	0.34
Pruning level (PL)	1	47.0	0.12	1	11.1	0.22
GT*PL	3	597.7	1.5	3	17.2	0.34
Error	34	399.6	-	35	51.0	-

Table 18A. ANOVA for total root fragment volume in Absaraka, ND, and Glyndon, MN, in 2009.

	Absaraka			Glyndon		
Sources of Variation	Degrees of freedom	Mean square	F-value	Degrees of freedom	Mean square	F-value
Rep	5	0.290	1.79	5	0.018	0.96
Grow tube treatment (GT)	3	0.136	0.84	3	0.004	0.22
Pruning level (PL)	1	0.030	0.19	1	0.007	0.38
GT*PL	3	0.235	1.45	3	0.007	0.37
Error	34	0.162	-	35	0.019	-

Table 19A. ANOVA total root fragment tips in Absaraka, ND, and Glyndon, MN, in 2009.

	Absaraka			Glyndon		
Sources of Variation	Degrees of freedom	Mean square	F-value	Degrees of freedom	Mean square	F-value
Rep	5	85736	2.73*	5	9925	0.98
Grow tube treatment (GT)	3	27597	0.88	3	16834	1.66
Pruning level (PL)	1	6620	0.21	1	4982	0.49
GT*PL	3	45821	1.46	3	5130	0.50
Error	34	31429	-	35	10168	-

* Significant at the 0.05 probability level.

Table 20A. ANOVA for average root diameter combined in Absaraka, ND, and Glyndon, MN, in 2009.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	0.0207	0.65
Pruning level (PL)	1	0.0371	0.88
GT*PL	3	0.0252	0.96
Loc*GT	3	0.0325	0.71
Loc*PL	1	0.0421	0.55
Loc*GT*PL	3	0.0262	0.57
Error	69	0.0457	-

Table 21A. ANOVA for bud break in Absaraka, ND, and Glyndon, MN, in 2010.

	Absaraka			Glyndon		
Sources of Variation	Degrees of freedom	Mean square	F-value	Degrees of freedom	Mean square	F-value
Rep	5	22.53	0.94	5	10.2545	1.91
Grow tube treatment (GT)	3	66.7	2.78	3	1.83661	0.34
Pruning level (PL)	1	38.7	1.61	1	0.02083	0.00
GT*PL	3	27.4	1.14	3	6.10764	1.14
Error	35	24.0	-	35	5.37760	-

Table 22A. ANOVA for plant survival combined in Absaraka, ND, and Glyndon, MN, in 2010.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	1.2639	1.75
Pruning level (PL)	1	0.1667	4.00
GT*PL	3	0.1111	0.42
Loc*GT	3	0.7222	1.55
Loc*PL	1	0.0417	0.09
Loc*GT*PL	3	0.2639	0.56
Error	70	0.4673	-

Table 23A. ANOVA for total nodes combined in Absaraka, ND, and Glyndon, MN, in 2010.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	94.9	1.72
Pruning level (PL)	1	7402.6	652.57*
GT*PL	3	12.1	0.36
Loc*GT	3	55.3	0.86
Loc*PL	1	11.3	0.18
Loc*GT*PL	3	33.434028	0.52
Error	70	64.10558	-

* Significant at the 0.05 probability level.

Table 24A. ANOVA for total viable nodes combined in Absaraka, ND, and Glyndon, MN, in 2010.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	40.355	4.57
Pruning level (PL)	1	0.235	0.26
GT*PL	3	2.006	3.03
Loc*GT	3	8.839	8.51**
Loc*PL	1	0.891	0.86
Loc*GT*PL	3	0.662	0.64
Error	70	1.039	-

** Significant at the 0.01 probability level.

Table 25A. ANOVA for node survival combined in Absaraka, ND, and Glyndon, MN, in 2010.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	0.0761	4.29
Pruning level (PL)	1	0.0564	774.18*
GT*PL	3	0.0035	1.65
Loc*GT	3	0.0177	5.88**
Loc*PL	1	0.0001	0.02
Loc*GT*PL	3	0.0021	0.70
Error	70	0.0030	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table 26A. ANOVA for the tallest viable node height combined in Absaraka, ND, and Glyndon, MN, in 2010.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	400.051	2.36
Pruning level (PL)	1	0.834	0.10
GT*PL	3	96.681	8.31
Loc*GT	3	169.190	4.25**
Loc*PL	1	8.347	0.21
Loc*GT*PL	3	11.632	0.29
Error	70	39.793	-

** Significant at the 0.01 probability level.

Table 27A. ANOVA for height survival combined in Absaraka, ND, and Glyndon, MN, 2010.

Sources of Variation	Degrees of freedom	Mean square	F-value
Location (Loc)	1	-	Not Valid
Replication(Loc)	10	-	Not Valid
Grow tube treatment (GT)	3	0.4851	18.09*
Pruning level (PL)	1	0.0006	0.46
GT*PL	3	0.0110	15.47*
Loc*GT	3	0.0268	3.43**
Loc*PL	1	0.0013	0.17
Loc*GT*PL	3	0.0007	0.09
Error	70	0.0078	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table 28A. ANOVA for stem number combined over 2008 and 2009 in Kindred, ND.

Sources of variation	Degrees of Freedom	Mean Square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment (Trt)	3	0.42014	0.40
Trt*Year	3	1.06250	2.34
Trt*Replication(Year)	12	0.45486	-
Variety (Var)	3	2.44792	2.14
Var*Year	3	1.14583	5.14**
Var*Trt	9	1.00579	1.83
Var*Trt*Year	9	0.55093	2.47*
Error B	48	0.22309	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table 29A. ANOVA for stem length combined over 2008 and 2009 in Kindred, ND.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment (Trt)	3	14952	2.39
Trt*Year	3	6269	1.14
Trt*Replication(Year)	12	5507	-
Variety (Var)	3	14949	12.19*
Var*Year	3	1227	0.48
Var*Trt	9	4078	1.99
Var*Trt*Year	9	2050	0.81
Error B	48	2530	-

* Significant at the 0.05 probability level.

Table 30A. ANOVA for Dormant Pruning Weights in Kindred, ND, in 2009 and 2010.

		2009		2010	
Sources of variation	Degrees of freedom	Mean square	F-value	Mean square	F-value
Replication (Rep)	2	15521	1.10	11058	0.23
Treatment (Trt)	3	22381	1.41	82704	0.95
Trt(Rep)	6	15901	1.12	86963	1.82
Variety (Var)	3	14667	1.04	232710	4.88**
Var*Trt	9	26280	1.86	46081	0.97
Error	24	14143	-	47713	-

** Significant at the 0.01 probability level.

Table 31A. ANOVA for Green Pruning Weights in Kindred, ND, in 2009.

		7/10/2009		8/4/2009		Total	
Sources of variation	Degrees of freedom	Mean square	F-value	Mean square	F-value	Mean square	F-value
Replication (Rep)	2	71282	1.01	35693	1.61	71759	0.540
Treatment	3	776765	8.04*	30232	0.43	1006169	4.250
Treatment(Rep)	6	96554	1.36	69863	3.16	236722	0.146
Variety	3	118348	1.67	50257	2.27	293129	0.114
Variety*Treatment	9	71678	1.01	11598	0.52	108235	0.609
Error	24	70763	-	22121	-	133083	-

* Significant at the 0.05 probability level.

Table 32A. ANOVA for bud break combined over 2009 and 2010 in Kindred, ND.

Sources of variation	Degrees of Freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment (TRT)	3	54.60	2.00
Year*TRT	3	27.34	3.94**
TRT*Replication(Year)	12	6.93	1.52
Variety (VAR)	3	25.69	1.59
Year*VAR	3	16.19	3.55*
VAR*TRT	9	8.65	1.76
Year*VAR*TRT	9	4.90	1.07
Error	48	4.57	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table 33A. ANOVA for July soil temperature in Kindred, ND, in 2008 and 2009.

	2008			2009		
Sources of variation	Degrees of freedom	Mean square	F-value	Degrees of Freedom	Mean square	F-value
Replication	2	0.270	2.69	2	34.8	0.92
Treatment	3	16.253	2.16**	3	41.4	1.09
Error	6	0.100	-	5	38.0	-

** Significant at the 0.01 probability level.

Table 34A. ANOVA for July soil water content in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	0.00076	0.81
Year*Treatment	3	0.00093	0.34
Error	12	0.00279	-

Table 35A. ANOVA for August soil temperature in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	11.105	2.07
Year*Treatment	3	5.369	19.64**
Error	10	0.273	-

** Significant at the 0.01 probability level.

Table 36A. ANOVA for August soil water content in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	0.000918	1.44
Year*Treatment	3	0.000637	0.17
Error	10	0.003792	-

Table 37A. ANOVA for September soil temperature in Kindred, ND, in 2008 and 2009.

		2008		2009	
Sources of variation	Degrees of freedom	Mean square	F-value	Mean square	F-value
Replication	2	0.692	1.71	5.501	1.02
Treatment	3	1.552	3.83	4.181	0.77
Error	6	0.405	-	5.401	-

Table 38A. ANOVA for September soil water content in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	0.000835	3.29
Year*Treatment	3	0.000254	0.09
Error	11	0.002878	-

Table 39A. ANOVA for October soil temperature in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	6.151	7.97
Year*Treatment	3	0.772	1.07
Error	12	0.722	-

Table 40A. ANOVA for October soil water content in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	0.00622	1.65
Year*Treatment	3	0.00376	1.88
Error	12	0.00200	-

Table 41A. ANOVA for November soil temperature in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	5.677	7.41
Year*Treatment	3	0.766	1.01
Error	12	0.758	-

Table 42A. ANOVA for November soil water content in Kindred, ND, in 2008 and 2009.

Sources of variation	Degrees of freedom	Mean square	F-value
Year	1	-	Not Valid
Replication(Year)	4	-	Not Valid
Treatment	3	0.00374	1.54
Year*Treatment	3	0.00243	1.21
Error	12	0.00201	-

Table 43A. ANOVA for spring bud survival in Kindred, ND, in 2009 and 2010.

Sources of variation	Degrees of freedom	Mean square	F-value
Replication	2	10.32	0.98
Treatment	3	20.67	2.57
Treatment(Replication)	6	8.04	0.76
Variety	3	32.00	3.03
Variety*Treatment	9	11.84	1.12
Error	18	10.57	-