Evaluating Maintenance Techniques for Long-term Vegetation Establishment on Disturbed Slopes in Alabama

by

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Abstract

Sustainability of common bermudagrass on formerly disturbed slopes in Alabama has proven to be a difficult task in some cases. Failures of once successful stands of bermudagrass can be seen throughout Alabama on road banks, borrow areas, and other formerly disturbed slopes. Failure of the permanent vegetation results in exposed soil subject to erosion as well as off-site sediment transport. In this research, selected maintenance techniques and environmental impacts are evaluated using outdoor plots of third year common bermudagrass. Part one of this research was conducted in 2010 at the E. V. Smith Research Center (EVSRC) located in Milstead, Alabama, and focuses on mowing height and herbicide application effectiveness to improve bermudagrass regrowth, as measured by Δ percent bermudagrass cover, while monitoring runoff for corresponding effects on turbidity and selected nutrient concentration. Mowing height treatments of 7.6 cm, 15.2 cm, and 22.9 cm (3, 6, and 9 in, respectively) were evaluated with and without herbicide application treatments. The 7.6 cm mowing height was found to significantly increase bermudagrass regrowth by 12 percent cover between individual cuttings. The 15.2 cm mowing height was found to significantly increase bermudagrass regrowth by 12 percent cover across the entire growing season. Herbicide application significantly increased bermudagrass regrowth compared to no-herbicide treatments with an increase of 6 percent cover over the entire growing season. Average turbidity values across all treatments and sampling dates was 28 NTUs. Mean nitrate, ammonium, and phosphate concentrations in runoff ranged from 0 to 5.3 mg/L, 0 to 4.0 mg/L, and 0 to 6.5 mg/L, respectively. There were no significant differences in turbidity values or nitrate, ammonium, and phosphate concentrations in runoff in response to mowing height or herbicide application treatments. Although the mowing height by herbicide interaction was not significant, it was concluded from this study that the herbicide applied 15.2 cm treatment was most conducive to increasing bermudagrass regrowth for long-term sustainability.

Part two of this research focused on a separate study located at the Turfgrass Research Unit (TGRU) located in Auburn, Alabama, to compare new digital image analysis (DIA) vegetation cover estimates with conventional line transect method cover estimates. The comparative study was performed on initial establishment of TifSport bermudagrass. Bermudagrass grow in data as a percent cover was collected using both the DIA and line transect methods and subsequently analyzed for correlation. A limited accuracy assessment of the DIA method using five digital photographs of calculated percent cover concluded that the DIA method adequately estimates vegetation cover (r = 0.999) compared to field measured grids of bare soil and bermudagrass. Independently collected paired line transect and DIA data on 52 plots at TGRU (n=352) did not express high correlation (r = 0.75). The line transect method over-estimated vegetation cover by 23%. It was concluded based on the higher correlation of the calibration study (1.00 vs. 0.75) that most of the variability in the paired data at TGRU was a result of observer subjectivity within the line transect method. Minimal DIA variability appeared to result from inter-pixel confounding. When comparing DIA to the line transect method estimates, results similar to Richardson et al. (2001) and Godinez-Alvarez et al. (2009) were found. The line transect method over estimated vegetation cover compared to the DIA method. Therefore, it was concluded from this study that DIA more adequately estimates vegetation cover than the line transect method.

Results from this study affirm the importance of proper maintenance procedures for sustainability of common bermudagrass on formerly disturbed slopes in Alabama, and indicate the need for further research for a better understanding of bermudagrass response to maintenance techniques. Findings in this study also demonstrate the need to further evaluate DIA as a means to quantify vegetation cover with a larger accuracy assessment.

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CHAPTER ONE

INTRODUCTION

1.1 EROSION AND SEDIMENT TRANSPORT IN CONSTRUCTION

Erosion is the process by which the earth's surface is worn away by the action of water, wind, and glaciers. Construction sites are susceptible to erosion due to the large amount of exposed soil. Sediment transported off-site is the most visible pollutant originating from nonpoint sources (NPS). Runoff controls are essential to prevent polluted construction runoff from reaching surface waters. There are many effects associated with excessive sediment loading which include diminished aesthetic value of streams and lakes, loss of storage capacity in reservoirs, and accumulation of bottom deposits leading to reduced food supplies and habitat for aquatic populations. The majority of urban and highway erosion is produced from exposed areas of soil during construction. Sediment yields in these disturbed areas can reach 50,000 Tonnes/km^2/yr (Novotny, 1981). The United States Environmental Protection Agency (USEPA) reported that soil erosion from construction sites was the largest contributor to NPS in the U.S. at a rate of 502,000 kg ha^{-1} yr^{-1} (USEPA, 2000)

Problems associated with erosion and sediment control are not limited to construction sites. Row crop agriculture is another major source of erosion. Conventional plowing can overturn as much as eight inches of soil. Disturbing large amounts of soil can lead to extreme cases of erosion. For example, the "dust bowl" in the 1930s was a result of poor farming practices on marginal lands in dry regions (Novotny, 2003). No-till agriculture helps reduce erosion by disturbing only the top two inches of soil (Dunn, 2011). Conventional tilled agricultural areas will likely continue to be a source of erosion because soil in this practice is necessarily disturbed for planting. Although a major contributor to NPS pollution, agricultural areas reportedly cause 37,600 kg ha^{-1} yr^{-1} of sediment loss, a relatively small amount when compared to estimated construction site losses (USEPA, 2000).

Vegetative cover is a major factor in reducing erosion on construction sites or any area of disturbed land. Vegetation serves as a protective barrier between the soil surface and the erosive elements of wind and water. Vegetative cover not only absorbs the energy of raindrops, vegetation binds soil particles, slows the velocity of runoff, and increases the ability of the soil to infiltrate water. Vegetative cover through evapotranspiration removes subsoil water after a rainfall, reducing potential for runoff in the succeeding rainfall event. Vegetation also reduces off-site fugitive dust carried by wind by reducing exposure to bare soil.

Establishing and maintaining vegetation on slopes poses greater challenges than on mild or level surfaces. The Alabama Department of Transportation (ALDOT) defines a steep slope as >3:1. Slope increases runoff velocity during rain events, resulting in potential transport of sediment but also seed, fertilizer, and temporary covers such as mulches, straw, and erosion control blankets. Although erosion is decreased once vegetation is established, it is not completely absent. Sparse vegetation helps bind soil particles but provides only minimal protection from shear stresses resulting from surface water velocity. Runoff velocities may be high as water passes between the stems of sparse vegetation. As early as 1935 Hjulström reported that as runoff velocities increase above 25 cm/s erosion begins to occur. It is widely accepted that dense stands of vegetation with many stems sprouting from the soil are most desired on slopes. However, once dense stands of vegetation are achieved on formerly disturbed slopes, maintaining those stands of vegetation then becomes the most important component of long term erosion control.

Maintaining long term vegetation on construction sites with slopes in Alabama has proven to be a challenging task. Failures of once successful stands of vegetation can be seen throughout Alabama on road banks, borrow areas and disturbed slopes. Failure of these permanent vegetation stands results in exposed soil which is subject to erosion as well as sediment transport off-site. The health of a stand of vegetation cannot be overlooked because vegetation is our best protection and first line of defense against soil erosion. Long term vegetation is in fact considered one of the best management programs to minimize soil loss from disturbed soil and steep slopes (Morgan and Rickson, 1995).

1.2 COMMON ROADSIDE VEGETATION IN ALABAMA

1.2.1 Desirable Vegetation

ALDOT currently specifies use of several different types of permanent vegetation for erosion and sediment control on right-of-ways in Alabama. This section reviews some of the common species of desirable vegetation used as permanent cover across the state by ALDOT.

Classification as a warm season or cool season and perennials or annuals are the four common characteristics used to describe grass and legume cover. Although grass is used as the dominant cover on most ALDOT right-of-ways (ROWs) legumes are also grown in mix to help prevent weeds and fix nitrogen in the soil. Cool season grasses thrive best when average daily temperatures are between 65° and 75°F. Warm season grasses tolerate average daily temperatures between 80° and 95°F. Whether vegetation species are perennial or annual depends on the life cycle length of the plant. Annuals complete their entire life cycle in one growing season growing from seed to bloom to seed set, and finally senescence in one growing season. Although annuals live for only one growing season, they produce seeds that may germinate the following growing season. Perennials live for more than two growing seasons. The top portion of most perennials dies back each winter, and then re-grows from the same root system the following spring.

Bermudagrass (*Cynodon dactylon*) is a warm season grass native to southeastern Africa (Ball et al., 1996) used widely throughout the southern third of the United States for erosion control, residential lawns, athletic fields, roadsides, and pastures. Bermudagrass is a perennial that has several characteristics that make it suitable for roadside vegetation. It has a deep root system which makes it extremely drought tolerant but it can also survive short-term flooding. The deep root system increases soil stability, mitigating erosion problems. Because bermudagrass is drought tolerant it does not produce significant biomass during dry conditions, reducing the need for maintenance mowing. Bermuda adapts well to many common soil types and its limited cold tolerance makes it well suited to the climate of the southern United States.

Bahiagrass (*Paspalum notatum*) is another warm season grass that is commonly used on lawns and roadsides in the southern US. Bahiagrass, like bermudagrass, is a drought tolerant perennial grass that is a suitable cover during dry summer months. Like bermudagrass, bahiagrass has a deep root system and is therefore a desirable grass for soil stabilization. In addition, bahiagrass, a native of South America, (Ball et al., 1996) is resistant to disease and insect attack. Stands of bahiagrass will sometimes thin and become susceptible to weed invasion, however bahiagrass is more tolerant to frequent mowing than bermudagrass due to its rapid vertical growth especially in the summer months.

Crimson clover (*Trifolium incarnatum*) a native of the Mediterranean (Ball et al., 1996) is a quick germinating annual legume. It is a perfect plant for providing quick cover as long as adequate moisture and mild temperatures are available. Crimson clover reseeds very well when it is allowed to mature and can grow up to 2 ½ feet tall. Crimson clover is typically planted in the fall and can tolerate a variety of soil types. It grows best in cool humid weather which makes it suitable as a spring and fall cover in Alabama.

Fescue (*Festuca arundinacea*), like crimson clover, is typically planted in the fall. It is a cool season grass that is native to Europe (Ball et al., 1996) that tolerates hot weather better than most cool season grasses. However, excessive heat and drought will thin fescue stands each summer. By tolerating various soil types and growing in shade as well as sun, fescue survives in many different environments. Its deep root system makes fescue another excellent candidate for erosion control. Healthy fescue stands grow into a desirable mat that will choke out and minimize weed competition.

Kobe lespedeza (*Kummerowia striata*) a native of Eastern China, Korea, and Japan (Ball et al. 1996) is another plant species well adapted to the south that serves many useful purposes including roadside vegetation. Kobe lespedeza is a warm season annual legume that is tolerant of poorer soil types. Two benefits of kobe are that it is easily and quickly established, and it has low maintenance requirements, including low lime and fertilizer requirements. Like bermudagrass and bahiagrass, kobe has a deep root system and is often used for erosion control. Kobe lespedeza is widely used in pastures for hay as well.

ALDOT specifies vegetation species or mix of species based upon three planting zones (Figure 1.1) in the state, hill slope, and expected mowing frequency as well as characteristics of the vegetation. ALDOT divides the state into three planting zones: zone 1 is northern Alabama, zone 2 is central Alabama, and zone 3 is southern Alabama (Figure 1.1).

Figure 1.1. ALDOT planting zones corresponding to climate, soil, and slope. (Alabama, 2011)

The three planting zones provide baseline information to determine what vegetation is best suited to a certain area. As the state's landscape and climate varies mainly from north to south, characteristics such as soil type, average land slope, and climate are the main differences between each zone. The three planting zones depicted in Figure 1.1 reflect these climatic and physiographic changes.

ALDOT commonly specifies mixtures of different seeds for permanent vegetation. Recommended mixtures for planting zone 1 can include lespedeza, bermudagrass, fescue, and crimson clover. Recommended mixtures for planting zone two can include bermudagrass, bahiagrass, lespedeza, and fescue. Recommended mixtures for planting zone 3 can include lespedeza, fescue, bermudagrass, bahiagrass, and crimson clover.

1.2.2 Undesirable Vegetation

Not all vegetation found on roadsides in Alabama is desirable. In fact, the invasion of weedy plants and species that do not have desirable characteristics is a common occurrence along roadsides in Alabama. Grasses that are competitive, have shallow root systems, tall growth habit, or have no aesthetic value are considered undesirable. This section provides several commonly found vegetation species in Alabama that are undesirable.

Johnson grass (*Sorghum halepense*) is the most common undesirable vegetation found on roadsides in Alabama. Johnson grass is a perennial native to the Mediterranean region (Ball et al., 1996) that can reach 6 ½ feet in height. The tall growth habit of Johnson grass shades out desirable permanent vegetation and poses a safety concern on roadways by obstructing the view of drivers. Johnson grass is one of the most troublesome weeds in agronomic and horticulture crops, as well as in pastures, hay fields, and roadsides. Johnson grass reproduces rapidly and easily overruns other vegetation in a variety of environments.

Dodder (*Cuscuta* spp.) is a perennial parasitic plant being found more frequently in recent years along roadsides in Alabama. Dodder is a twining yellow or orange plant that is sometimes tinged with purple or red. It parasitizes other plants such as alfalfa, lespedeza, flax, clover, and potatoes. Shortly after germinating, dodder finds a host plant and twines itself around the plant’s stem. Its water, minerals, and carbohydrates are absorbed from the host plant. Although dodder rarely kills the host plant, it does stunt the growth of its host reducing the plants health in the long term.

Another grass that can take over a stand of permanent vegetation if not treated is crabgrass (*Digitaria* spp.). Crabgrass is a warm season annual native to Southern Africa (Ball et al., 1996). Abundant moisture in early summer can promote germination of crabgrass. Later summer droughts do not affect crabgrass because it can tolerate both drought and compacted soils once established. Crabgrass is considered a weed as it grows into mats which choke out desirable vegetation. Crabgrass is not aesthetically pleasing and is hard to control making it undesirable.

1.3 ALABAMA ROADSIDE VEGETATION MAINTENANCE PROCEDURES

ALDOT is one of the largest, if not the largest, earth moving entity in Alabama. In recent years ALDOT has contracted about $1.3 billion in construction each year. In any given year, ALDOT typically has 300-400 active construction contracts. ALDOT currently manages approximately 11,000 miles (28,000 lane miles) of road and right-of-way and 15,525 bridges.

Currently ALDOT has several maintenance practices in place to enhance vegetation growth of desired grass species in highway right-of-ways (ROW). Practices such as herbicide application, mowing, fertilization, and reseeding are used to maintain stands of grass on right-of-ways.

Herbicide applications are used by ALDOT crews to remove undesirable species or “weeds” and reduce competition for the desired species (ALDOT, 2008). Different herbicides including glyphosate and sulfosulfuron are used depending on the planting zone, the target species, and the grass species desired.

Mowing is typically done on ALDOT ROWs two to three times a year when vegetation has reached a height of approximately 16 inches. Typically, a six inch finished mowing height is the target. The three typical mowing times are: 1) In May to take off winter growth, 2) In July/August to cut warm season growth, and 3) In October/November as a clean-up mowing. Mowing is done any other time when vegetation becomes a hazard to motorists and as necessary to promote growth of the required permanent species (ALDOT, 2008).

Leaving poorly established areas exposed could lead to erosion and compaction of the soil surface. According to ALDOT specifications a well established stand of vegetation is defined as having at least 80% cover (ALDOT, 2008). Reseeding projects are done in areas where the permanent vegetation was not well established or where the permanent vegetation does not currently provide adequate cover to prevent erosion.

Typically percent vegetation cover is evaluated by visual measurements, making measurements subjective and variable from one evaluator to another. This lack of an objective repeatable method to analyze percent vegetation cover could lead to controversy between ALDOT representatives and contractors being paid to install permanent vegetation.

1.4 JUSTIFICATION OF RESEARCH

A third year stand of common bermudagrass at the E. V. Smith Research Center (EVRSC) was established in 2008 on 21 plots for long-term assessment of bermudagrass stands on 4:1 slopes in Alabama. At the end of year two the stands had decreasing bermudagrass cover and increasing weed invasion. The cause was unknown. ALDOT staff and other stakeholders had previously reported similar problems occurring on ROWs in Alabama. As a result, the challenge of failed stands was addressed specifically with respect to maintenance techniques. Mowing height and its effect on long term vegetation and management was already an uncertainty of ALDOT. Herbicide application is a common practice used by the ALDOT maintenance division to minimize weed competition; however, herbicide effectiveness was another uncertainty of ALDOT. Therefore, it was decided to pursue a replicated third year maintenance study evaluating both herbicide application and mowing height treatments to determine the best treatment for vegetation management on slopes.

1.5 RESEARCH OBJECTIVES

The overall goal of this research was to determine if different mowing heights and herbicide application significantly affect the regrowth and runoff quality of a third year stand of common bermudagrass on a 4:1 slope in Alabama. The specific objectives of this research are to:

1. Evaluate mowing heights of 7.6, 15.2, and 22.9 cm (3, 6, and 9”) to determine if there were significant differences in mean regrowth of a third year stand of common bermudagrass.
2. Determine if the application of the herbicide MSMA for weed suppression had a significant effect on mean third year bermudagrass regrowth.
3. Determine if mowing height or herbicide application has a significant effect on soluble inorganic nitrogen, phosphorus, ammonium concentration or turbidity in plot runoff.
4. Compose a post-processed digital photographic method of cover estimation to standard field techniques for cover estimation using independent bermudagrass cover data.

1.6 ORGANIZATION OF THESIS

This thesis is divided into five chapters. Chapter 1 provides an introduction to the research topic followed by research objectives. Chapter 2 provides a literature review pertaining to soil erosion by water, roadside maintenance, and digital image analysis research. Chapter 3 describes the methods used to complete research objectives. Chapter 4 presents research results using alternate maintenance practices to evaluate response on bermudagrass regrowth, and nutrient runoff and turbidity. Included in chapter 4 are comparative results of digital image analysis (DIA) to quantify vegetation cover versus conventional cover estimates. Chapter 5 summarizes research project findings and recommendations, presents overall conclusions and provides recommendations for future research relating to maintenance practices on right-of-ways in Alabama. Recommendations related to the potential for digital image analysis as a viable cover estimation method are also provided. Reference and Appendices sections are provided at the end of the thesis.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Much advancement has been made in the reduction of both point source and nonpoint source pollution. Point source pollution is identified as pollution that can be traced to a direct location or point of discharge such as a traditional pipe effluent. Nonpoint source pollution is identified as all other diffuse pollution that is not point source pollution (Novotny, 2003).

Changes in the hydrological characteristics of watersheds have been occurring rapidly over the last 30 to 40 years due to a term referred to as *urban sprawl. Urban sprawl* occurs when large quantities of agricultural land are converted to subdivisions and other urban land uses with larger areas of imperviousness (Novotny, 2003). For example, between 1960 and 1990, the population of the Baltimore metropolitan area increased by 33%. Increasing five times faster by 170% was the amount of land used for urban and suburban living areas such as subdivisions (Katz, 1994). Increased urbanization is a result of increased population. Major consequences of increased urbanization are that increasing impervious area decreases infiltration and increases the risk of flooding and resulting nonpoint source pollution.

Industrial wastewater was a major source of pollution in U.S. waterways before promulgation of the Clean Water Act (CWA) in 1972. Before the CWA, there was little or no regulation of wastewater discharge; and industries could discharge incompletely treated wastewater directly into a river or stream. The cumulative affects of toxic chemicals caused reduced populations of fish and other aquatic life, some species becoming extremely scarce. The

National Pollution Discharge Elimination System (NPDES) permit system in 1972 regulated the quantity of pollution an industry could discharge into a given receiving water. Subsequently, point source dischargers had to obtain a permit before discharging wastewater (Novotny, 2003).

In 1972, the U.S. Congress enacted the Water Pollution Control Act Amendments (the Clean Water Act, PL 92-500). Section 101(a) of the act states: “The objective of the Act is to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters.” Pollution was dramatically reduced in the United States over the 1980s and 1990s as a result of amendments to the CWA (Novotny, 2003).

2.2 EROSION PROCESS

Understanding the process by which erosion occurs is an important factor in determining how to prevent it. Soil erosion can be classified as natural or accelerated. Natural erosion is a geological process over which man has little or no control (i.e. Grand Canyon). Any place that man has disturbed the soil and erosion occurs faster than it would naturally can be considered accelerated erosion. Construction is a major source of accelerated erosion. Construction site erosion must be controlled, minimized, and maintained during as well as after construction is completed. According to the *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Area* (2009), erosion and runoff are influenced by the combination of climate, topography, soils, vegetative cover and the extent of land disturbance.

Climate includes rainfall, temperature and wind. Rainfall frequency, intensity and duration are the major factors affecting the potential for water erosion and sediment transportation. An increase in intensity, duration and runoff volume results in an increase in the ability of water to detach and transport soil particles (Alabama, 2009).

Topography is characterized by the shape and slope of an area. As slope length and gradient increase, so does the potential for erosion and sediment transportation due to likelihood of gullies and other concentrated flows (Alabama, 2009).

Soil texture, structure, organic matter content and permeability are all elements that affect a soil’s erosivity. Sandy and silty soils located on steep slopes are extremely susceptible to erosion because they lack the cohesiveness of more clayey soils. Clays, along with organic matter, act as a binder to soil particles which reduce erodibility. Although clays are not as easily eroded, once the particles are detached they are unfortunately easily transported. Small clay particles called colloids remain in suspension for long periods of time and are a major source of turbidity in runoff water (Alabama, 2009). Turbidity is the cloudiness or haziness of a fluid caused by individual particles or suspended solids present in the fluid.

Vegetative cover acts as an energy dissipater between falling raindrops and the soil surface (Alabama, 2009). In addition to intercepting rainfall and runoff, it has been reported that grass species increase water infiltration and resistance to erosion by stabilizing the soil structure with their root systems (Li et al., 1992a, 1992b; Pan and Shangguan, 2006). Temporary covers such as straw and hay are used not only to protect the soil surface from the direct force of raindrops but also to protect the seed on newly planted areas from being washed away. As the permanent vegetative cover is established, the temporary cover decomposes and is no longer needed.

In the erosion process, soil particles are detached from the soil mass and transported to another location. Raindrops impacting the soil at high velocities are the first step in the erosion process (Beasley, 1972). Soil erosion is the result of rainfall on an inadequately protected area and is also caused by water running over bare soil which carries soil particles away from their original location and deposits them in a new downslope location. The rate of removal of the soil particles is proportional to the intensity and duration of the rainfall as well as to the water flow volume and characteristics and the soil properties (AASHTO, 1982). Wind erosion is another form of soil erosion that will not be discussed due to the objectives of this research project. The deposition of transported soil by water occurs when water velocity decreases and the transport capacity of the flowing water becomes insufficient to carry the entire sediment load.

Several studies have shown that increasing grass cover percentage can reduce soil loss and runoff (Liu et al., 2010; Dyrness, 1975; Grace; 2002; Morschel et al., 2004). In this study artificial road sections were constructed 2.0 m long, 0.55 m wide, 0.35 m deep and were positioned on a 15° slope. The sections were packed with loessial soil (1.5 g/cm^3) and planted with the various grass coverages of 0, 30, 40, 50, 60, and 70%. Decreased amounts of sediment loss and runoff were reported to be the direct result of grass intercepting and dissipating the raindrop energies before impacting the soil surface. Increasing grass coverage meant increasing the amount of raindrop energy dissipated across the plots. Runoff decreased from 12.4 – 27.9% and sediment yield decreased from 39 – 76% when compared to the bare soil plots (Table 2.1) (Liu et al., 2010).

Table 2.1. Runoff and sediment yield rate reductions due to vegetation coverage (Liu et al., 2010)

Vegetation Coverage (%)	Runoff Reduction* (%)	Sediment Yield Red.* (%)
0		
30	12.4	39
40	15.5	47
50	21.7	59
60	24.8	65
70	27.9	76

*Compared to bare soil plot

2.3 EROSION SEVERITY

2.3.1 Raindrop Erosion

The first step in the erosion process is the detachment of soil particles caused by raindrops impacting the ground surface at high velocity. As a raindrop impacts the bare soil surface, the area directly under the raindrop is compacted, which results in reduced infiltration into the soil. The raindrop also explodes soil granules, reducing particle size, allowing for easier transport off-site. The exploding effect moves detached soil particles in an outward direction from the center of the impact. If the raindrop impact occurs on a slope, more than half of the detached soil can be moved downslope as it falls back to the surface (Beasley, 1972). Once the rate of rainfall exceeds the rate of infiltration, the depressions found on the soil surface fill and cause runoff resulting in transport of particles by water.

2.3.2 Sheet Erosion

Sheet erosion is characterized by soil movement resulting from both raindrop splash and surface runoff. Sheet erosion moves lighter soil particles, organic matter, and soluble nutrients and is therefore considered to be highly detrimental to soil fertility and productivity. It is easy for sheet erosion to go unnoticed until most of the productive topsoil is lost due to the uniform losses that occur across a slope. All runoff water takes the path of least resistance. As the water concentrates in depressions it gains velocity downslope as the volume of water and slope of land increases (Beasley, 1972).

2.3.3 Rill Erosion

Surface runoff concentrates in every little depression and eventually forms a small but well-defined channel. These small channels are called rills if they do not interfere with normal tillage operations (Beasley, 1972). Rills allow for increased water velocities which in turn allow for larger soil particles to be transported off-site.

2.3.4 Gully Erosion

If the rills erode to the point that they cannot be removed by normal tillage operations, they are referred to as gullies. Gullies are formed as the result of several factors. Surface channels are one way gullies are formed. Water concentrated into a channel can simply erode until a gully is formed. Waterfalls also result in gully formation. Water flowing over a sudden change in grade has increased eroding power as compared to the same stream on a uniform grade. As gullies erode and become deeper channels, the gully bank becomes susceptible to slides or soil mass movement from the gully bank to the channel bottom. Soil lost in gully erosion is of less value than that lost in sheet erosion because it is made up primarily of subsoil

(Beasley, 1972). However, damage due to the loss of massive soil volumes and tillable acres is in most cases irreversible.

2.3.5 Channel Erosion

Large channels such as streams carry runoff water downslope through the path of least resistance. As the path of the stream curves and turns the water erodes the stream bank below the water level. With time the stream channel erodes to the point that the stream bank is completely undermined. This usually results in bank failure, depositing more sediment into the stream channel. Over long periods of time, channel erosion can result in appreciable loss of productive and valuable land (Beasley, 1972).

2.4 EROSION RESEARCH

2.4.1 USLE/rusle

The Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith, 1965) was originally the Universal Soil Loss Equation (USLE) designed to estimate erosion rates. The USLE was developed using many years of soil loss data from approximately 10,000 soil erosion test plots throughout the U.S. USLE was developed to predict soil loss in tons per acre per year. Test plots were 72.6 ft long and placed on 9% slopes. The RUSLE was developed in order to incorporate new research data into the program (Wischmeier and Smith, 1978). Although the basic form of the equation remained the same, modifications to several of the factors were made.

The RUSLE is based on the assumption that soil erosion is limited by the carrying capacity of the flow and not by the source of eroding material. As the sediment load reaches the carrying capacity of the flow, no more sediment can be detached and transported. Also, sedimentation occurs as the flow rate decreases and the runoff hydrograph is on its receding stage (Novotny and Chesters, 1981).

The RUSLE relates the rate of erosion per unit area (A)(tons/ac/yr) to the erosive power of the rain (R), the soil erodibility (K), the land slope and length (LS), the degree of soil cover (C) and specified conservation practices (P):

$$A = (R)(K)(LS)(C)(P) \qquad \text{(eq 1)}$$

The parameters of the equation are related linearly. Therefore, as one parameter is changed, the erosion yield is similarly changed. The *LS*, *C*, and *P* factors have a default value of 1.0. The values are changed based on different site conditions and site management strategies. RUSLE is designed to predict long-term average annual soil loss carried by runoff from specific management conditions. Neither RUSLE nor USLE estimate sediment yield (CPESC, 2007). Both are designed only to estimate erosion rates.

2.4.2 Erosion and sediment yield research

Areas of disturbed land that produce problems with erosion and sedimentation were once attributed to agricultural practices (i.e. dust bowl in 1930s). However, erosion and sediment yield is also proving to be a major environmental concern in the area of construction. Willet (1980) estimated that approximately five billion tons of sediment reached U. S. surface waters annually. Thirty percent of the sediment was attributed to natural erosion while the remaining 70 percent was attributed to human activities. Half of the 70 percent was generated from croplands and only ten percent was generated by construction. Although only ten percent of the sediment that reached U. S. surface waters was attributed to urban construction, in the 1970s urban construction only occurred on about 0.007 percent of the U. S. land (Willet, 1980). Increased development in many areas of the U. S. in recent years has only served to increase the need for construction site erosion controls (Pitt et al., 2007). With water quality standards and regulations becoming more stringent, new and more effective ways of controlling erosion and sediment transport are being evaluated. There are many current best management practices (BMPs) that are implemented to control erosion and sediment transport off-site.

Structural BMPs such as silt fences, sediment basins, and check dams are installed to reduce runoff velocity in order to allow deposition to occur on-site. Event planning BMPs such as minimizing the disturbed area by managing construction timing are also used in accordance with structural BMPs to minimize erosion and sediment transport. Vegetation, as stated earlier, is an important factor in erosion and sediment control. Retaining existing vegetation or planting new vegetation cover helps limit detachment and protect the soil surface from erosion.

The positive effects of vegetation cover on erosion can be seen in many different studies, as deforested areas of land are known to produce large amounts of sediment. Woo et al. (1997) reported that bare (deforested) rills in South China, when compared with vegetated (forested) rills, produced significantly higher flow volumes as well as sediment yield from rainfall. Rainfall interception was concluded to be the reason for reduced runoff flow volumes and sediment yield in the vegetated rills. Authors also noted that the vegetation promoted infiltration which further lowered surface flow. Reduced sediment yields in the vegetated scenario were subsequently attributed to lower surface flows along with the binding effect of the root systems in the vegetated rill.

Grass strips are also often used on disturbed slopes to reduce runoff velocity, filter flow, and promote infiltration. A study was conducted by Ligdi and Morgan (1995) in a laboratory experiment using metal rods to simulate grass planted in strips. The use of metal rods to simulate grass plants has been shown to yield acceptable representation of field conditions with the advantage of eliminating variability between individual plants. This study revealed that grass strips with a plant density of around 3,000 plants/m^2 can reduce sediment concentrations by up to half compared to bare soil control plots on slopes of 5 and 10% (Ligdi, 1995). It was also found that the offsite sediment yield reduction was due mainly to increased deposition in the ponded area above the simulated grass barrier. Adversely, grass strips on slopes of 20% or greater were found to increase erosion by a factor of two. Resulting accelerated erosion could be the result of concentrated flow between the individual plant elements (Ligdi, 1995). For this reason it was reported that grass strips are not recommended as effective under concentrated flow conditions (Ligdi, 1995). Liu et al. (2010), reported that as grass cover increased, overland flow was obstructed by the individual plant stems. This resulted on significantly lower mean flow velocities across the slope. The contradiction between the studies by Liu et al. (2010) and Ligdi (1995) could be the result of metal rods simulating grass cover. The metal rods lack the capability of natural grass root systems to provide soil stability on steeper slopes.

Unpaved roadways are commonly found on construction sites and are susceptible to extreme soil erosion and sediment transport. Bare surfaces typically channel runoff flow into borrow or other ditches on the roadsides or into ruts that have been created by vehicles on the roadway itself. Planting vegetation on unpaved roadways has been found to reduce erosion and sediment yield (Liu et al., 2010). Cao et al. (2006) reported that soil erosion on unpaved roads with no grass vegetation was three times greater than that of unpaved roads with grass vegetation. The economic benefit of seeding roads with grass was also evaluated in this study. It was found that grass vegetated road design costs 47% more than non-vegetated road design but 72% less than stone road design. Although vegetated road design costs more than bare roads, average road maintenance costs were reduced by 61% due to the reduction in eroded areas.

Therefore, vegetation of roads has been proven to be a sufficient aid as an erosion and sediment control BMP.

2.4.3 Nutrients in runoff

Nutrient runoff is common where fertilizer has recently been applied to land surfaces. Nutrients applied can be carried in runoff to nearby streams and lakes and pose an environmental threat to aquatic wildlife and their habitat. Nutrients can also contaminate groundwater that is used for drinking water. Fertilizer commonly used in agriculture and horticulture typically contains nitrogen (N), phosphorous (P), and potassium (K). Reseeding operations in construction practices typically defer to agronomic seeding and fertilizer practices. Prevalent nutrients in runoff are most usually in the form of nitrates and phosphates.

Inorganic nitrogen can exist in different forms; as a gas (N_2), nitrate (NO_3^-), nitrite (NO_2^-), or ammonia (NH_3). Nitrate reactions in water can cause oxygen depletion which can be harmful for fish and other aquatic species that depend on oxygen to survive. Nitrates are a major source of "blue baby syndrome" when consumed in large concentrations. The EPA standard for maximum concentration of nitrate in drinking water is 10 mg/L (U.S. EPA, 2009). The nitrates in water are transformed to nitrite in the digestive system. The nitrite oxidizes iron in the hemoglobin in human blood to produce methemoglobin which reduces the ability of red blood cells to transport oxygen (Oram, *2011*). If not converted to nitrates, nitrites are considered very dangerous in water. Nitrites are not only harmful to humans but also produce a fish condition called "brown blood disease". The fish react similar to humans as nitrite concentrations increase. The methemoglobin reduces the ability to transport oxygen (Chappell, 2008). The fish experience low oxygen stress and suffocate because their blood cannot carry oxygen. The drinking water standard for nitrite concentration is 1 mg/L (U.S. EPA, 2009).

Ammonia (NH_3) is toxic to aquatic life. This is not to be confused with ammonium (NH_4^+) which is relatively harmless to aquatic life. The chemical equation that represents the relationship between ammonia (NH_3) and ammonium (NH_4^+) is shown below.

$$NH_3 + H_2O \rightleftarrows NH_4^+ + OH^- \qquad \text{(eq 2)}$$

When the pH of the water is low the equation is driven to the right to produce ammonium. When the pH of the water is high the equation is driven to the left to produce ammonia which is harmful for aquatic life. There are many factors that can affect the pH of a water body. Some of these factors include: soil composition, bedrock, organic material in the water body, chemicals, and acid precipitation (Oram, 2011).

Phosphorus combined with oxygen in nature produces phosphate. Phosphate is carried in surface flow runoff to nearby streams and lakes. The initial increase in phosphorus can be good for the water body because the phosphorus increases algal growth and primary production. However, excess phosphorus in a freshwater body can result in a nutrient imbalance leading to eutrophication. The addition of substances such as nitrates and phosphates through fertilizers and sewage to a freshwater system are common. Eutrophication is characterized by the overproduction of algae as a result of increased nutrients. When the algae dies off, the high levels of organic matter and decomposing organisms usually results in loss of oxygen in the system which negatively affects the aquatic life (Novotny, 2003).

BMPs such as mulching, conservation tillage or non-tillage, terracing, and vegetated buffer strips, which are similar to those used for erosion and sediment control are used to control nutrient runoff as well. Grass strips can be used to reduce flow and promote infiltration. Also the grass can reduce nutrient runoff by utilizing the nutrients for food. Owino et al. (2006) performed a study on a clay loam soil in Kenya to see if planted grass strips would effectively control nutrient loss. Two different grass types were evaluated; Vetiver (*Vetiveria zizanioides*) and Napier (*Pennisetum purpureum*). When compared with the control, Napier grass, a perennial, reduced phosphate (PO_4), nitrite (NO_2), nitrate (NO_3) and ammonium (NH_4) loads by 55, 70, 45, and 47%, respectively. The warm season perennial, Vetiver, grass reduced these same nutrients by 11, 35, 11, and 0%, respectively. Napier grass performed more effectively due to the quicker establishment of a grass barrier than the Vetiver grass. The growth of the Vetiver was hindered by colder weather in which the grass did not grow well. The grasses' reduction in runoff was similar to the reduction of the nutrient loads. Reduction in nutrient loss from the treatments was not the result of changes in nutrient concentration in the runoff, but was controlled by volume of runoff (Owino et al., 2006). The Napier grass reduced runoff by 54% while the Vetiver reduced runoff by 12% (Owino et al., 2006).

2.5 ROADSIDE VEGETATION MAINTENANCE RESEARCH

2.5.1 Mowing Height

Little research has been done in the area of different mowing heights with regard to maintenance of roadside right-of-ways vegetation. However, some research has been done with regard to different mowing heights in the area of turfgrass. This section will review results from some of the studies dealing with different turfgrass mowing heights.

Bermudagrass is not only used as roadside vegetation, but also is grown for the production of hay. A study was conducted by Aiken et al. (1991) in Auburn, Alabama to determine the effect of mowing heights on the quality of bermudagrass hay. Three mowing heights evaluated were 2.5, 10.2, and 17.8 cm (1, 4, and 7 in. respectively). Mowing frequency was evaluated at 1, 2, 3, 4, and 6-week intervals over a 12-week period. The study measured bermudagrass total yield, protein content, and digestible organic matter. A 4-week mowing interval is generally assumed to produce good quality bermudagrass hay under normal yields. It was reported that increasing the mowing interval did increase yield but decreased the quality of bermudagrass hay for forage. Higher mowing heights improved the quality of bermudagrass hay forage by increasing digestible organic matter by 5.5 %, however yields decreased. There appeared to be no advantage to mowing higher than 10.2 cm. (4 in.) because the yields were decreased without further enhancement of forage quality (Aiken et al., 1991).

Several turfgrass studies have evaluated the effects of mowing heights on turf quality. Tucker et al. (2006) reported that increasing mowing height from 3.2 to 4.0 mm increased root length density (RLD) and root surface area (RSA) by 11% on ‘Tifeagle’ bermudagrass. Overall turf quality was also increased by 17%. Increasing RLD and RSA improved the plants ability for water and nutrient uptake which resulted in a higher quality plant. Similarly, Guertal et al. (2006) reported that higher mowing heights, 3.9 and 4.8 mm (0.154 and 0.189 in, respectively), had a positive effect when compared to the lower mowing height of 3.2 mm (0.126 in) on the establishment of ‘Tifeagle’ bermudagrass. The lowest mowing height, 3.2 mm, was reported in this study to reduce turfgrass color, rhizome, and stolon mass when compared to the higher mowing heights. Reducing rhizomes and stolon mass hinders the ability of the vegetation to achieve full coverage quickly (Guertal et al., 2006).

Since nutrient runoff can affect water quality characteristics of nearby streams and lakes, several studies have been conducted to determine if different vegetation heights affect nutrient runoff down slope. Specifically, a study was conducted by Moss et al. (2006) to determine if bermudagrass buffers 5.5 m long x 12.2 m wide mowed at increasingly higher heights could reduce nutrient runoff from golf course fairways better than bermudagrass buffers mowed at a single height. Grass buffers were placed at the bottom of six plots. Three of the buffers were mowed to a single height of 51 mm. The other three were mowed at increasingly higher heights of 25, 38, and 51 mm as the surface elevation decreased. Runoff was collected during 4 natural rainfall events as well as 6 irrigation events for 60 minutes after runoff was initiated. Moss et al. (2006) reported that bermudagrass buffers of increasing heights resulted in 17% less N, 11% less P concentrations, and 19% less runoff volume during 60 minutes of natural rainfall runoff. The graduated buffers of multiple heights also reduced N and P concentrations by 18% and 14% respectively, as well as runoff volume by 16% during 60 minutes of irrigation. In both cases, natural rainfall and irrigation, N and P concentrations were reduced along with runoff volume. Since the nutrient concentration multiplied by runoff volume results in the nutrient load, then the resulting N and P loads from this study were reduced.

2.5.2 Herbicide

Weed invasion occurs along roadsides in Alabama. ALDOT currently applies herbicide as a maintenance procedure to decrease weed competition with the desired species on right-of-ways in Alabama (ALDOT, 2008). Different herbicides including glyphosate and sulfosulfuron are used depending on the planting zone, the target species, and the grass species desired.

Glyphosate is a broad spectrum, non-selective systemic herbicide. It is effective on almost all annual and perennial plants (EXTOXNET, 1994). Manuja et al. (2005) reported that glyphosate was an effective post-emergence herbicide, killing a broad spectrum of weeds belonging to different genera. Glyphosate is only slightly toxic to wild birds. The LC50 value for mallards and bobwhite quail is 4,500 ppm. Glyphosate is generally non-toxic to fish with LC50 values for rainbow trout and bluegill sunfish of 38 and 120 mg/L, respectively (EXTOXNET, 1994).

Sulfosulfuron is a selective, systemic sulfonyl urea herbicide absorbed through both roots and leaves. It acts as an inhibitor of amino acid biosynthesis thus stopping cell division and plant growth. Sulfosulfuron has a toxicity classification of class III in that it is moderately irritant to skin and non-irritant to the eyes (Gharda, 2008).

Monosodium methanearsonate (MSMA) is another herbicide used for post-emergence weed control. Is an arsenic based herbicide and fungicide; however it is a less toxic organic form of arsenic and has replaced the role of lead hydrogen arsenate in agriculture. MSMA is a common herbicide used on golf courses and is typically used for the control of grassy weeds such as crabgrass. Jordan et al. (1997) reported that MSMA was a vital component in post-emergence directed herbicide sprays for morningglory and sicklepod. MSMA also controls yellow nutsedge, common cocklebur, and annual grasses, and it suppresses rhizomatous johnsongrass (Buchannan, 1992).

2.6 DIGITAL IMAGE PROCESSING

Methods to perform digital image analysis for measuring vegetation cover are becoming more common (Laliberte et al., 2007; Bennet et al., 2007; Richardson et al., 2001). Techniques to quantify the percentage of vegetative cover along with bare soil through digital photography could prove to be a more accurate and economical way to measure vegetative cover than ground based measurements. Currently there are two ground based plot measurements such as line point intercept and grip point intercept that are completed to determine percent cover. These techniques are labor intensive and very time consuming. Once fully developed image-based techniques will likely be faster and more economical. Also, being able to quickly acquire digital photos allows for easy assessment of vegetation dynamics throughout the monitoring process (Laliberte et al., 2007).

Digital image analysis (DIA) has traditionally been performed using pixel based image analysis. This is where each pixel has a digital number and is assessed individually. Digital images only have three bands, red, green, and blue (RGB). Because band inter-correlation is relatively high in the RGB space it is difficult in some cases to differentiate between live and dead plant material (Laliberte et al., 2007). Consequently, images can be transformed to the intensity-hue-saturation (IHS) space a color representation based on a color sphere rather than a color cube as in RGB space (Jensen, 2005). The vertical axis of the sphere represents intensity which relates to the brightness. The circumference of the sphere represents hue which is the dominant wavelength of the color. And finally, the sphere's radius represents saturation which is defined as the relative purity of the color (Jensen, 2005). Projects where initial vegetation cover is being evaluated should not be as susceptible to inter-correlation as projects where vegetation other than the desired species is present because there are two distinct colors to be represented: brown (bare soil) and green (vegetation cover). The study presented in this paper tests imaging procedures using initial vegetation establishment and is therefore expected to have minimal inter-correlation between live vegetation, dead/dormant vegetation, and bare soil.

There are a few studies that reported IHS transformations resulted in higher accuracy than digital images during vegetation analysis. Ewing and Horton (1999) used IHS transformations to estimate wheat canopy cover. Also, Karcher and Richardson (2003) used IHS transformations for quantifying turf grass cover. In 2001 Richardson et al. reported that digital imaging analysis could accurately measure the amount of green turf in a chosen turfgrass area. Hue and saturation values from preliminary work performed by Karcher and Richardson were used in this study to identify green pixels in the images. Since preliminary work was needed to determine a range of color tones that represent green pixels, it is expected that the IHS method will be more time consuming than other methods.

In the 2001 study by Richardson et al. the number of green pixels was divided by the total number of pixels for the image to result in percent turf grass cover. This study was an evaluation of initial cover establishment. Therefore, the only color evaluated was green (vegetation cover). Pixels that were not identified as green were simply disregarded but were counted towards the total number of pixels in the image.

Other methods of determining turfgrass cover were compared with the DIA method by Richardson et al. (2001). The line intersect analysis (LIA) and subjective analysis (SA) methods were also used. The LIA method analysis was performed by superimposing a grid system onto the same images used from the IHS transformation. The number of intersects where the desired plant material is found is then multiplied by the area of each grid section and divided by the total sample area for a percentage of each species. A subjective analysis involves frequent subjective ratings performed by trained evaluators. Although it has been found that there can be extreme variation with this method, subjective evaluations are still being used.

The mean variance of percent cover by DIA (0.65) was significantly lower than SA (99.12) or LIA (13.18) (Richardson et al., 2001). Consequently, Richardson et al. (2001) reported that DIA was an effective way of producing both accurate and reproducible estimates of turf grass cover. Also, the technique removes the inherent error and evaluator bias commonly associated with subjective ratings.

CHAPTER THREE

MATERIALS AND METHODS

3.1 SITE OVERVIEW (PART I)

The study was conducted at the E. V. Smith Research Center (EVSRC) which was established in 1978 by Auburn University with an area of 1544 ha. The EVSRC is located at Exit #26 on interstate 85 in Milstead, Alabama 25 miles south of Auburn (Figure 3.1). E. V. Smith has research units dedicated to dairy cattle, beef cattle, horticulture, plant breeding, field crops, and biosystems engineering. The predominant soils for the sites at EVSRC consist of Cowarts loamy sand and Malbis fine sandy loam.

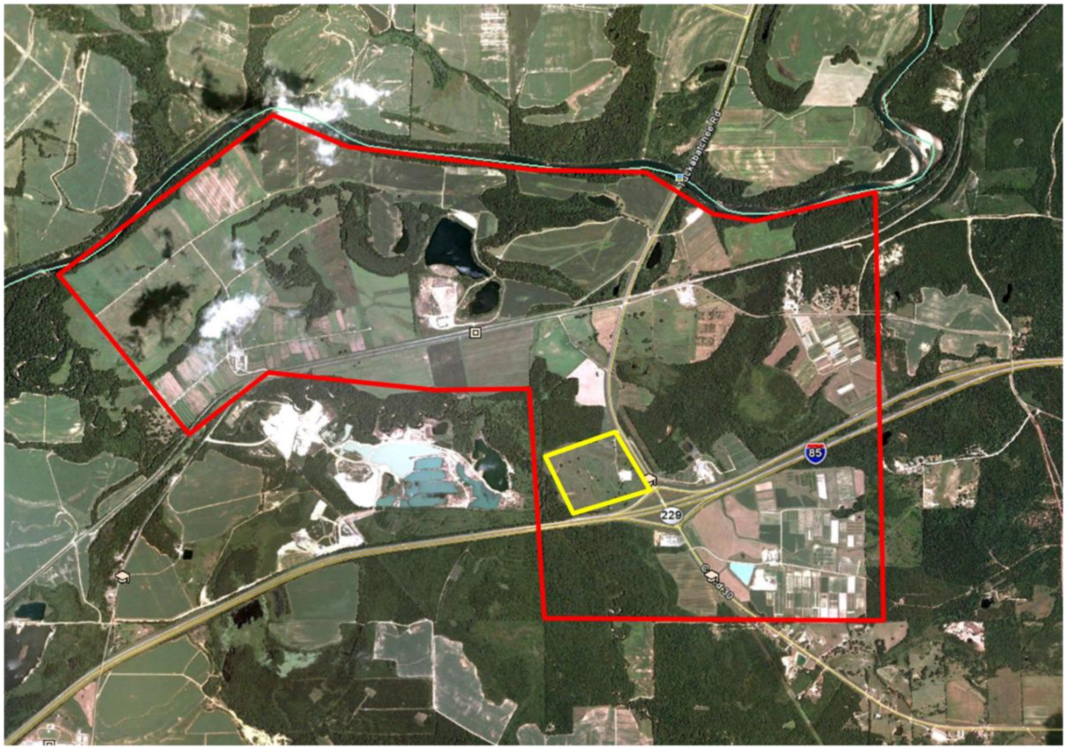


Figure 3.1. E.V. 1544-ha Smith Research Center (red). Project site shown in yellow.

Twenty-one erosion control plots 3 m x 8 m (10 ft x 25 ft) were constructed in 2007 at the project site (Figure 3.1) with seven plots on a north facing slope and the other fourteen plots on a west-southwest facing slope (Figures 3.2 and 3.3). Plots were constructed on 4:1 slopes and separated by 1.5 m (5 ft) grassed alleys. Each plot was seeded with common bermudagrass (*Cynodon* datctylon) in 2008. Diversion swales were constructed to direct upslope water around the plots. A gutter system and downspout was installed on each plot to collect plot runoff.

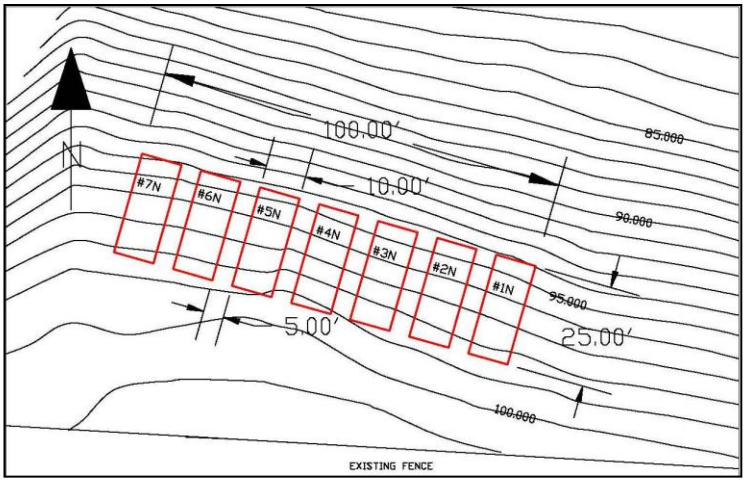


Figure 3.2. Seven north facing plots on 4:1 slopes.

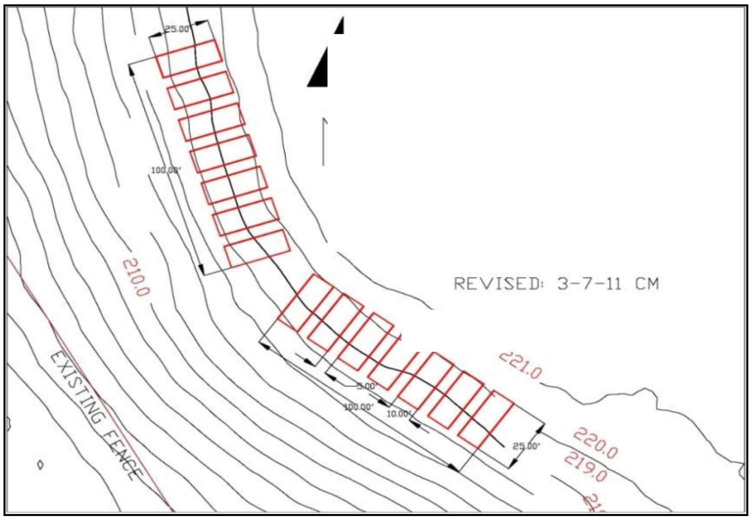


Figure 3.3. Fourteen west-southwest facing plots on 4:1 slopes.

3.2 EXPERIMENTAL SETUP

During the 2010 growing season, three mowing heights were evaluated on the third year stands of common bermudagrass: 7.6 cm, 15.2 cm, and 22.9 cm (3, 6, and 9 in respectively). The three selected mowing heights were applied with and without the application of herbicide to create six independent treatments (Table 3.1). ALDOT mows right-of-ways with a target vegetation height of 15.2 cm (6 in) and currently applies herbicide in an effort to decrease weed competition. The 15.24 cm (6 in) mowing height with herbicide application was therefore considered the control treatment because it most closely corresponds to current ALDOT practice. The six treatments shown in Table 3.1 were replicated three times and randomly assigned to 18 of the 21existing plots at EVSRC. Study plots were those with relatively high vegetation uniformity, minimal weed competition, and adequate runoff sampling hardware performance. Plots with higher percent bermudagrass cover and less weed competition were selected and considered to be the most suitable for the study. Plots observed with signs of runoff undermining the gutter runoff collection system were excluded from the experiment.

Table 3.1. Six mowing height and herbicide treaments

	7.6 cm (3 in)	**15.2 cm (6 in)**	**22.9 cm (9 in)**
No Herbicide	NH3	NH6	NH9
Herbicide	H3	H6 (control)	H9

The treatment descriptions are as follows: NH3 - 7.6 cm (3 in) mowing height with no-herbicide application, H3 - 7.6 cm (3 in) mowing height with herbicide application, NH6 - 15.2 cm (6 in) mowing height with no-herbicide application, H6 - 15.2 cm (6 in) mowing height with herbicide application, NH9 - 22.9 cm (9 in) mowing height with no-herbicide application, H9 - 22.9 cm (9 in) mowing height with herbicide application.

Soil fertility tests from the Auburn University Soil Testing Laboratory revealed that no additional fertilizer was needed for the establishment of bermudagrass used on roadsides. However, a nitrogen (28-0-0-5, liquid fertilizer) maintenance application was applied to all plots at a rate of 89.6 kg/ha (80 lbs/ac) on June 3, 2010, according to agronomic recommendations.

Runoff was collected from all 18 study plots during rainfall events. Previous studies on the plots (Baharanyi, 2010) indicated that a rainfall depth of at least 0.2 inches was needed before runoff could be collected in the automated samplers. In the present study, storm runoff when present was sampled after every rainfall event as described in section 3.6 then taken back to the lab to be tested for turbidity and nutrient concentrations.

3.3 MOWING HEIGHT

Each treatment plot was cut to one of three mowing heights: 7.62 cm, 15.24 cm, and 22.86 cm (3, 6, and 9 in respectively). A Craftsman 55.9 cm (22 in) push lawn mower was used to perform the mowing height applications. The lawn mower was powered by a Briggs and Stratton 4.1 kW (5.5 hp) 158 cc engine. In order to mow at 15.24 and 22.86 cm the lawn mower deck was retrofitted with metal brackets (Figures 3.1a, b, and c).

Plots were mowed at the appropriate mowing height three times during the study: June 7, 2010, July 15, 2010, and September 9, 2010. Plots were mowed using a walk-behind mower parallel to the contours to maximize operator safety and so that grass clippings remained on the plots. Most importantly, mowing along the contour was an effort to mimic current ALDOT maintenance practices.

(a) (b) (c)

Figure 3.4. Mowing heights of 7.62, 15.24, 22.86 cm (3, 6, 9 in), respectively.

3.4 HERBICIDE APPLICATION

Herbicide applied to all plots designated to receive treatment was monosodium methanearsonate (MSMA) applied at a rate of 2.35 liters per ha (2 pints per acre). Application of MSMA was made on June 2, 2010 using a CO_2 backpack sprayer with a hand boom (Figure 3.4). The backpack sprayer with attaching 2.44 meter (8 ft) hand boom was selected for mobile application and to minimize herbicide drift onto plots not designated for herbicide application.

Figure 3.5. Herbicide application with backpack sprayer and 2.44 m (8 ft) hand boom.

3.5 BERMUDAGRASS COVER (PART I)

3.5.1 Data Collection and Sub-sampling

Among the 18 plots selected for this research, vegetation uniformity varied both between plots and from the top to bottom of each plot. The upslope sections of these third year bermudagrass stands appeared upon initial inspection to have the highest percent cover of the desired species, bermudagrass. The average initial percent cover of the 18 study plots measured from the top, middle, and bottom sub-plots was 56 ±27, 34 ±19, and 15 ±14 percent, respectively. Thus, it was evident that percent bermudagrass coverage decreased from the higher plot slope position to the toe of the slope. With a P-value = <0.0001 from the ANOVA, it was concluded from Tukey grouping that the initial cover at each of the three sub-plot locations was significantly different. Consequently, each plot was separated into three sub-plots: Top, Middle, and Bottom. Quantifying bermudagrass cover separately in all three sub-plots was done to more accurately compare bermudagrass cover between the top and bottom sub-plots of each treatment while also increasing the sample size by a factor of three. Division into sub-plots also facilitated representative sampling of bermudagrass regrowth throughout the season-long study.

Bermudagrass cover throughout the season was measured biweekly using the line transect method, also called the line-point intercept method (Godinez-Alvarez, 2009). The line transect method was performed by stretching a string having 25 evenly spaced marks across two diagonals of each sub-plot (Figure 3.5). Each mark represented a sample point to be tallied. The string point was viewed from directly above and analyzed as if a raindrop were to land in the position of the mark. The type of vegetation or cover was recorded. Example responses included bermudagrass, crabgrass, dead vegetation, and bare soil. Both diagonals represent 50 tally points per sub-plot. The tallied points were doubled to obtain a 100 point total representing percent coverage for each sub-plot. The line transect method is commonly used to estimate vegetation cover at both large and small scales. Godinez-Alvarez et al. (2009) used the line transect method with four 70 m transects spaced a minimum of 10 m along a 70 m baseline to analyze the foliar cover in a study area in the Chihuahuan Desert. Foliar cover was recorded every 1 m for a total of 70 points per transect. Godinez-Alvarez et al. (2009) reported that the results from the line transect method were significantly higher than subjective ocular estimates. Ocular measurements were made by observing the foliar cover and estimating the percent cover; no equipment or standard other than evaluator experience was used to assess cover with the ocular method. In recognition of observer variance, all measurements in the Godinez-Alavarez study were completed by two highly experienced field technicians. In the current study at EVSRC, one observer completed all observations.

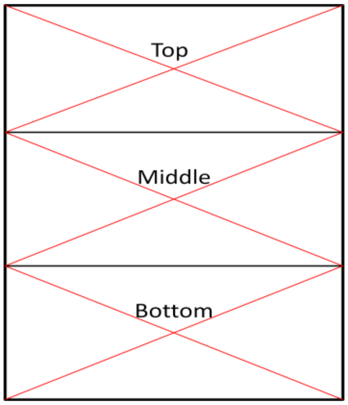


Figure 3.6. String placement for the line transect method (red lines)

3.5.2 Data Analysis

Mowing heights of 7.6, 15.2, and 22.9 cm (3, 6, and 9 in respectively) were analyzed across inter-mowing periods 1, 2, and 3 (39 days between 6/7/10 and 7/15/10, 57 days between 7/15/10 and 9/9/10, and 34 days between 9/9/10 and 10/12/10, respectively). A total of 1188 cover measurements were taken at the EVSRC grow-in study; 18 plots x 3 subplots x 2 string/subplot x 11 measurement dates. The change in bermudagrass cover is identified as Δ percent bermudagrass cover (i.e. final percent cover – initial percent cover = Δ percent cover) and is defined as bermudagrass regrowth. Mean Δ percent bermudagrass cover was analyzed during each inter-mowing period for significant differences between mowing height and herbicide application treatments. The three inter-mowing periods were also analyzed together as one dataset for significance between mowing heights and herbicide application. Grouping the three inter-mowing periods together increased the sample size by a factor of 3. After each mowing date, the bermudagrass cover measurement was considered the initial percent cover for that inter-mowing period. The bermudagrass cover measurement taken before the next mow date was considered to be the final percent cover.

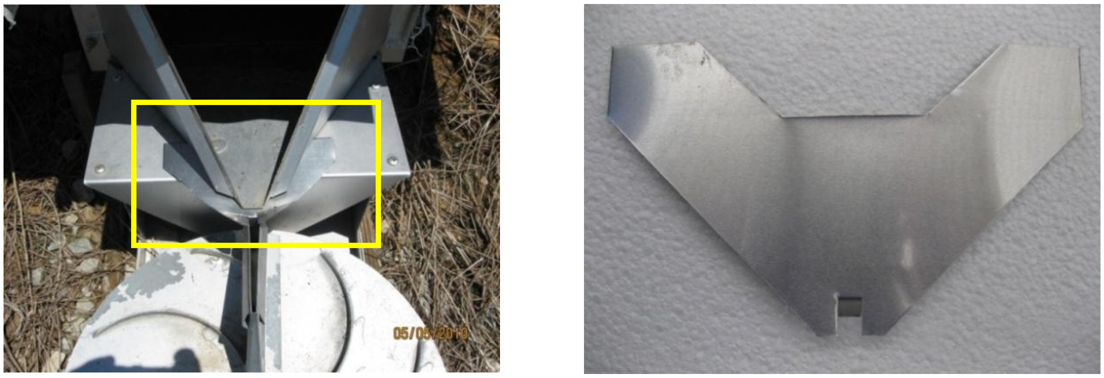
Bermudagrass regrowth for all three mowing heights of 7.6, 15.2, and 22.9 cm (3, 6, and 9 in respectively) was also analyzed as one "long term" interval from the beginning to the end of the growing season. The initial measurement of bermudagrass cover taken on May 17, 2010 was subtracted from the final bermudagrass cover measurement taken on October 12, 2010 for each comparison made to produce a single estimate of bermudagrass regrowth over the entire 149 day growing season.

Mean "long term" and "short term" Δ percent bermudagrass cover results were analyzed for significant differences between treatments and then compared for differences between short and long term results.

3.6 RUNOFF SAMPLING

The gutter system and downspout installed at the bottom of each plot directed runoff to individual Coshocton wheels for sampling (Figure 3.7). The Coshocton wheels installed downslope on plots at EVSRC are designed to capture 1/100th of total runoff from each plot into a 20-liter (5-gallon) bucket. A previous study of the erosion control plots at EVSRC experienced minimal runoff volume during smaller rainfall events as a result of vegetation grow in (Baharanyi, 2010). In anticipation of low runoff volumes due to permanent vegetation establishment the Coshocton wheels were locked into place (Figure 3.8a) with a small piece of sheet metal (Figure 3.8b) in order to capture as much runoff as possible. Locking the Coshocton wheels in place effectively disabled runoff volume determination from the plots. Rather, buckets were allowed to overflow since runoff volume was not an objective in this study. Only turbidity and nutrient concentrations (nitrate, ammonium, and phosphate) were analyzed in runoff because of environmental and regulatory interest on impact to receiving streams. The 20 liter sampling buckets were sampled after each of 11 rainfall events between May 10, 2010 and August 31, 2010.

Figure 3.7. Newly installed gutter system, Coshocton wheel, and 20L sampling bucket for runoff sampling in 2008 at EVSRC (Baharanyi, 2010).



(a) (b)

Figure 3.8. Coshocton wheel locked in place to capture up to 100 percent runoff (a) and device used to lock wheel into place (b).

A standard rain gauge (Stratus^{TM} RG202, Fergus Falls, MN) (Figure 3.9a) and a tipping bucket (NovaLynx Corporation, Auburn, CA) (Figure 3.9b) were used to collect precipitation data. Precipitation depth to the nearest 0.0254 cm (0.01 in) was recorded after each rainfall event using the Stratus RG202. A HOBO Pendant Event/Temp Data Logger UA-003-64 (Onset Computer Corporation, MA) unit was configured to record the tipping bucket rainfall data as 0.0635 cm per tip (0.025 in per tip). HOBOware software Version 2.7.1 (Onset Computer Corporation, MA) was used to download precipitation data from the tipping bucket to the computer. The rainfall data was exported to an excel file where the number of bucket tips were counted and cross referenced to the recorded storm event time, to determine rainfall duration and intensity. In characterizing the number of rainfall events used to calculate rainfall intensity, each rainfall was considered to be a new event if one hour had elapsed since the previous rainfall event.

(a) (b)

Figure 3.9. Standard rain gauge (a) and data logging tipping bucket (b).

Runoff samples were collected immediately after transferring collected plot runoff into a second 20-liter bucket to completely mix the sample and resuspend sediment particles that had settled in the bottom of the bucket (Figure 3.10a). Runoff samples were then collected from the second bucket using a 125 mL bottle (one sample per bucket) (Figure 3.10b).

(a) (b)

Figure 3.10. Transferring runoff into second bucket and then pulling representative sample.

3.7 WATER SAMPLE ANALYSIS

Turbidity was analyzed using a Hach model 2100P portable turbidimeter (Loveland, CO). Unfiltered samples were analyzed using a 15 mL small glass vial equipped with the turbidimeter. In the laboratory, the 125 mL bottles with unfiltered runoff sample were shaken to resuspend sediment and then poured into the 15 mL turbidimeter vial for analysis. The 15 mL runoff sample was analyzed for turbidity after which the container was rinsed with distilled water to prevent contamination between sample readings. The turbidimeter was calibrated before sampling began and was recalibrated periodically according to manufacturer recommendations. Approximately 110 mL of runoff sample left in the 125 mL bottle was frozen for subsequent nutrient analysis.

For subsequent nutrient analysis, frozen samples were thawed then filtered through a 45 micron filter with a vacuum pump. Nitrate ($N0_3$), ammonium (NH_4), and phosphate (PO_4) concentrations were analyzed from each plot runoff sample using the microplating procedure (Sims et al., 1995). This procedure was performed by placing a small amount of a water sample into a microplate cell with reagents depending on the analytical method. A microplate is a small plastic tray approximately 7.5 x 11.5 cm with 96 cells used to analyze different runoff samples (Figure 3.11). The program Gen5^{TM} Data Analysis Software was used to analyze absorbance values for each microplate cell based on pre-mixed nitrate, phosphate, or ammonium standards included in each microplate. Nitrate, phosphate, and ammonium standards were supplied from the laboratory where the microplating procedure was performed. With one calculation each absorbance was transformed into a concentration value (mg/L). Along with the absorbance values, the analytical software provided coefficients (A and B) that were used in conjunction with absorbance values to determine the concentration level for each microplate cell (eq 3). A different water sample was analyzed in each microplate cell.

$$\text{Concentration (mg/L)} = \text{Absorbance (A)} + \text{B} \qquad \text{(eq 3)}$$

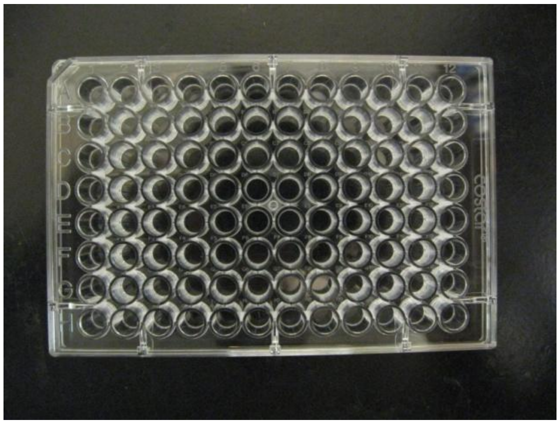


Figure 3.11. 7.5 x 11.5 cm microplate tray with 96 cells used for individual cell nutrient concentration analysis.

3.8 DATA ANALYSIS FOR BERMUDAGRASS GROW-IN STUDY AT EVSRC

3.8.1 sas Procedures

The percent cover data for each sampling date determined by line transect method from plots at EVSRC were recorded and organized into an excel spreadsheet. The difference in each sub-plot's percent cover for each inter-mowing period was calculated as a Δ percent cover. The Δ percent cover was used to quantify bermudagrass regrowth response for the inter-mowing periods (i.e. short term) and for the seasonal growth (i.e. long term). The Δ percent cover data was organized by subplot treatment and replication throughout the study. Means of data were first analyzed graphically to determine any trends evident in the data. Basic statistical summaries including means were developed for preliminary comparison and further conclusion.

The Statistical Analysis Software (SAS® 9.22) was subsequently used to determine if there were any significant differences in the means of Δ percent bermudagrass cover and runoff data between successive mowing height and herbicide treatments. A 2 x 3 factorial analysis (2 herbicide x 3 mowing height) of variance (ANOVA) was performed using the General Linear Model (PROC GLM procedure). Turbidity and runoff responses required a log transformation

(SAS, 2011). Tukey grouping analysis was conducted to determine significant differences between mowing height and herbicide application response. Interactions were also tested between mowing height and herbicide response. An alpha value of 0.05 was used for all statistical comparisons.

3.8.2 Statistical Hypotheses

Objective one of this research was to evaluate the mowing heights of 7.6, 15.2, and 22.9 cm to determine if there was a significant difference in mean bermudagrass regrowth. The null hypothesis for this objective was that there were no significant differences between the mean bermudagrass regrowth values of the mowing heights. The alternate hypothesis for objective one was that the mean bermudagrass regrowth of at least one mowing height was significantly different from the other two mowing heights. The statistical hypothesis for objective one in this research study was:

$$H_o: \mu_{7.6cm} = \mu_{15.2cm} = \mu_{22.9cm}$$

$$H_A: \mu_{7.6cm} \neq \mu_{15.2cm} \neq \mu_{22.9cm}$$

Results are discussed in Chapter 4, indicated by P-values < 0.05, that there was a significant difference in mean bermudagrass regrowth for the 7.6 cm and 15.2 cm mowing heights.

Objective two of this research was to determine if the application of herbicide MSMA had a significant effect on bermudagrass regrowth. The null hypothesis for this objective was that there was no significant difference between the mean bermudagrass regrowth between the herbicide treatments. The alternate hypothesis for objective two was that the mean bermudagrass regrowth for the herbicide treatments were significantly different from each other. The statistical hypothesis for objective two in this research study was:

$$H_o: \mu_H = \mu_{NH}$$

$$H_A: \mu_H \neq \mu_{NH}$$

Results are discussed in Chapter 4, indicated by P-values < 0.05, that there was a significant difference in mean bermudagrass regrowth between the herbicide treatments.

Objective three of this research was to determine if either mowing height or herbicide application had a significant effect on soluble inorganic nitrogen, phosphorus, ammonium concentration or turbidity in plot runoff. Multiple statistical hypotheses were needed for this objective. One null hypothesis for objective three was that mean soluble inorganic nutrient concentrations and/or turbidity values were not significantly different as a result of mowing height. The alternate hypothesis was that mean soluble inorganic nutrient concentrations and/or turbidity values were significantly different as a result of mowing height. One of the statistical hypotheses for objective three in this research study was:

$$H_o: \mu_{7.6cm} = \mu_{15.2cm} = \mu_{22.9cm}$$

$$H_A: \mu_{7.6cm} \neq \mu_{15.2cm} \neq \mu_{22.9cm}$$

The second null hypothesis for objective three was that mean soluble inorganic nutrient concentrations and/or turbidity values were not significantly different as a result of herbicide treatment. The alternate hypothesis was that mean soluble inorganic nutrient concentrations and/or turbidity values were significantly different as a result of herbicide treatment. The second statistical hypotheses for objective three in this research study was:

$$H_o: \mu_H = \mu_{NH}$$

$$H_A: \mu_H \neq \mu_{NH}$$

Results are discussed in Chapter 4, indicated by P-values > 0.05, that there were no significant differences for mean nutrient concentrations or turbidity in runoff for the different mowing height or herbicide treatments.

3.9 DIGITAL IMAGE ANALYSIS (PART II)

A separate DIA study was conducted at the Turfgrass Research Unit (TGRU) in order to compare and evaluate a DIA method to the line transect method. The objectives for the current DIA comparison study were completely separate from the study at EVSRC (Part I). The DIA analysis was not used on the EVSRC study plots or data. Initial establishment of a TifSport bermudagrass was monitored at TGRU using the line transect method to quantify bermudagrass cover. It was important to quantify a full range of vegetation cover (0% cover – 100% cover) when comparing the two methods. It was for this reason that the initial bermudagrass establishment study was selected to evaluate the DIA method. Digital photographs of a 0.5 x 0.5 meter section of the plots were taken on the same dates as the line transect data for comparison. The initial establishment of TifSport bermudagrass used in the comparison study was a nitrogen rate application study conducted by Dr. Elizabeth Guertal of Agronomy and Soils Department. The study began at the TGRU in May 2010 with 13 different nitrogen rate applications. The plots were planted in early May 2010 and the nitrogen response study continued through June 25, 2010 until 100 percent cover was observed. Nitrogen rate treatments were replicated four times for a total of 52 1.83 x 2.44 meter (6 x 8 ft) plots. The plots were monitored once per week to assess the response, if any, of nitrogen rates on bermudagrass establishment.

Bermudagrass cover values (percent) were determined using the line transect method, nearly identical to the method used for bermudagrass cover determination of the 18 plots located at the EVSRC. The only difference was that the string with marks at the TGRU study was stretched across only one diagonal. The string had a total of 20 marks and therefore the results had to be multiplied by five to estimate the total percent coverage out of 100 percent. Also, a skilled agronomist conducted the line transect method at TGRU, including in the method plant material all green and yellow/brown bermudagrass stems as bermudagrass cover.

352 photographs used for digital image analysis were taken using a conventional Canon *Power Shot A590 IS* with 8.0 megapixels. The photographs were taken from a height of approximately 1.067 meters (3.5 ft). A 0.5 x 0.5 meter frame was laid on the ground and used in the photograph to provide a standard reference area for each digital photograph. The pictures were subsequently cropped to 0.5 x 0.5 meter before digital analysis (Figures 3.12a and b). The frame was placed at the same location each week (northwest corner of each plot) that pictures were taken. All photographs were taken during the same time of day under similar light conditions to reduce variability between photographs. The line transect data was measured from the bottom right corner to the upper left corner of each plot.

3.9.1 Digital Image Analysis

All 352 digital photographs were analyzed using Hypercube 32 software (USAGC, Alexandria, VA). This analytical software is used by the U. S. Army to determine the area occupied by building tops, parking lots, and other surfaces in aerial photographs. There are many other commercial and research applications of this public domain software such as food quality analysis.

(a) **(b)**

Figure 3.12. Digital photograph taken before and after photo cropping.

The software assigns a vector number of three numerical components red, green, and blue (RGB) to each pixel when analyzing color images. Training pixels are selected by the user to represent a domain color (i.e., green pixel for live vegetation, brown pixel for bare soil) and assigned an identifying number (i.e. 1, 2, 3, etc). The user then selects an additional four pixels, totaling five pixels, inside the classification window for each training pixel selected. Each pixel's vector value from the original photograph is compared against the selected training pixels. If the pixel's vector value falls within the range of any training pixel then it is classified as that identified training pixel. The user can output a histogram with the number of pixels classified for each training pixel. By dividing the number of classified pixels for each training pixel by the total number of pixels classified the user can get an estimate of percent cover provided for that color domain or combination of domains.

There is no standard method provided for the use of Hypercube 32 in digital assessment of vegetation. Consequently, a methodology was developed in the present study and applied to analysis of each digital photograph, as follows. First a total of six training pixels were selected from each photograph (Table 3.2). Training pixels one and two represented leaf blades and bermudagrass seedheads and training pixels three and four represented bermudagrass stolons and rhizomes (Figure 3.13). A light green color was selected for training pixel one and a dark green color was selected for training pixel two to represent green bermudagrass vegetation. A light yellow color was selected for training pixel three and a dark yellow color was selected for training pixel four to represent yellow bermudagrass vegetation. Some of these pixels include bermudagrass undergrowth. A light brown color was selected for training pixel five to represent bare soil. A dark brown color was selected for training pixel six to also represent bare soil.

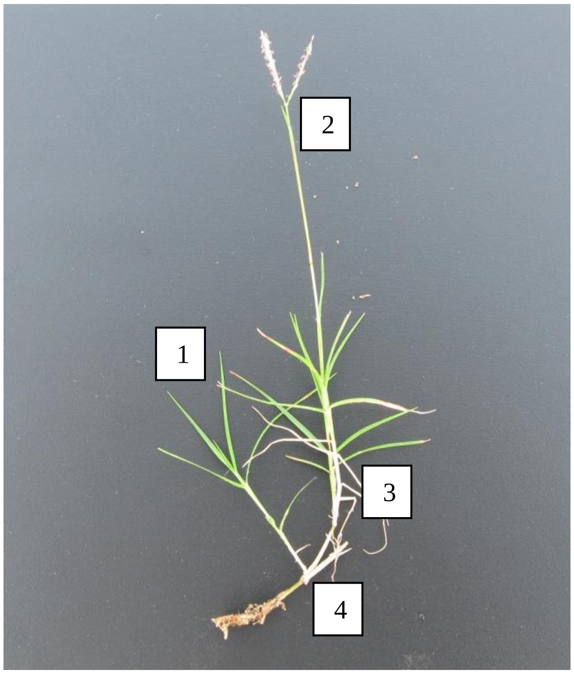


Figure 3.13. 1 – bermudagrass leaf blade, 2 - bermudagrass seedhead, 3 – bermudagrass stolon, 4 - bermudagrass rhizome.

Table 3.2. Training pixel number with its representation and pixel color.

Training Pixel #	Training Pixel Represents	Pixel Color Selected
1	bermudagrass leaf blade	Light green
2	bermudagrass seedhead	Dark green
3	bermudagrass stolon	Light yellow

4	bermudagrass rhizome	Dark yellow
5	Bare Soil	Light brown
6	Bare Soil	Dark brown

After classification by Hypercube, the pixel count for each of the six training pixels was divided by the sum of the total pixels classified to determine the total percent cover for each training pixel. The sum of total pixels classified by DIA was divided by the total number of pixels that made up the original photograph. As part of the methodology, a rule was set that 90 percent of the pixels from each original photograph had to be classified by DIA. This 90 percent rule insured that an adequate number of pixels from each photograph were classified. 100 percent classification of all pixels in the original photograph was uncommon due to pixels that have vector values outside the range of the six training pixels. For example, dark pixels such as shadows were the most common pixels to not be classified because the dark coloration did not resemble any of the training pixels. If more than 10 percent (i.e. < 90% classified) of the original photograph's pixels were not classified the photograph was not included in the comparative dataset. Including photographs with an inadequate (i.e. < 90% classified) percentage of pixel classification could result in inaccurate comparative data.

Results in terms of total percent cover for training pixels one and two were added together to represent bermudagrass leaf blades and seedheads. Training pixels three and four were added together to represent bermudagrass stolons and rhizomes. Training pixels five and six were added together to represent bare soil. The pixel count for training pixels one through four were subsequently added together to represent all plant material and provide an estimate of total bermudagrass cover. The total percent cover values for the DIA method were graphically compared to the total cover values for the line transect method. A regression line was fitted to the data to determine the correlation between the line transect method estimates and the DIA method estimates of total bermudagrass cover.

3.9.2 Data Analysis

Each of the 352 pictures taken at TGRU had a corresponding bermudagrass cover estimate formulated from line transect and DIA methods. All estimates were organized in excel and graphed with the cover estimate response from DIA on the y axis and the corresponding line transect estimates on the x axis. A line of slope 1:1 was displayed to demonstrate ideal correlation. An ANOVA table and regression line was formulated using the regression data analysis tool in excel. Findings from the regression analysis regarding data correlation and accuracy are presented in Chapter 4, showing the relationship between estimates produced from DIA method versus the line transect method.

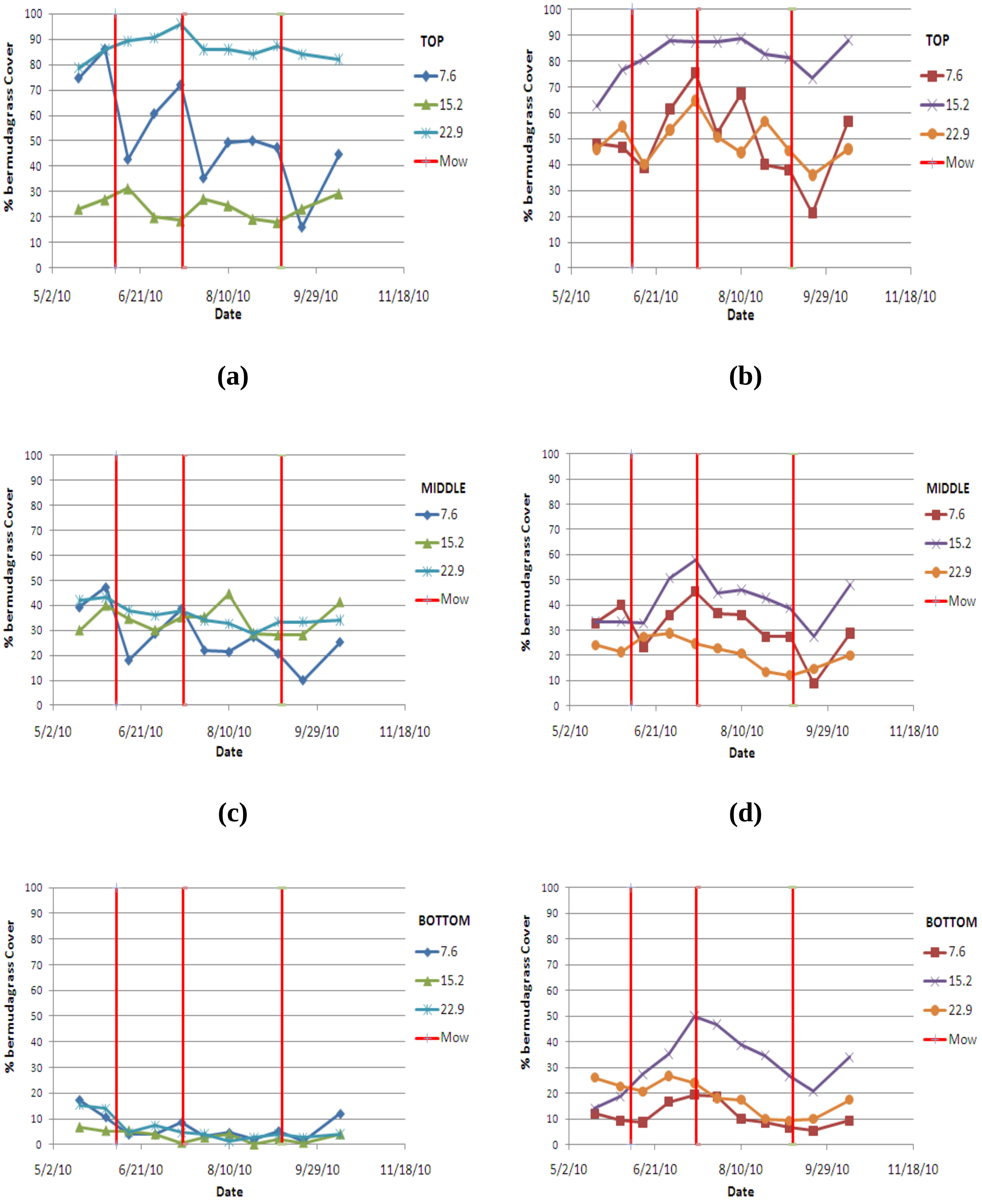
CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 BERMUDAGRASS COVER

4.1.1 *Mowing Height - Short Term Analysis*

Bermudagrass cover at the EVSRC was evaluated to determine if mowing height or herbicide application had a significant effect on mean bermudagrass regrowth, as measured by the line transect method. Figures 4.1 (a-f) display the average bermudagrass cover of each treatment throughout the five month study. Cover measurements were taken biweekly throughout the 2010 summer season. The immediate negative impact of mowing (shown as red vertical lines) on percent bermudagrass cover can be seen in the figures. After each mowing date (6/7/10, 7/15/10, and 9/9/10), the average bermudagrass cover decreased in15 of 18 cases. This decrease in average bermudagrass cover was likely a result of grass clippings remaining on the plots as well as bermudagrass growth being clipped from the stems. The main response used in this study was the change in (Δ) percent cover measurements between mowing dates (i.e. areas between the red lines). These areas will be referred to as inter-mowing periods one (6/7/10 – 7/15/10), two (7/15/10 – 9/9/10), and three (9/9/10 – 10/12/10). Lines that have positive slopes between the red line in Figures 4.1(a-f) indicate increased bermudagrass cover. Steeper lines indicate greater bermudagrass regrowth. Figures 4.1(a-f) indicate varied third year bermudagrass response to mowing height and herbicide treatment across the five month growing season.



(a)

(b)

(c)

(d)

(e)
No-Herbicide Application

(f)
Herbicide Application

Figure 4.1. Mean bermudagrass cover for top, middle, and bottom subplots by mowing height (n=3). Vertical red lines represent mowing dates (6/7/10, 7/15/10, 9/9/10).

The third year bermudagrass had an increase in cover after the first mowing on 6/7/10 as indicated in Table 4.1. Five out of six treatments showed an average increase in bermudagrass regrowth which are indicated by positive Δ percent bermudagrass cover values. In Table 4.1 there were only three decreasing mean Δ percent bermudagrass cover values, represented by negative values. Of the three negative values, two were observed from a no-herbicide 15.2 cm (NH6) treatment. The herbicide 7.6 cm (H3) treatment produced the largest mean Δ percent bermudagrass cover with an increase in bermudagrass cover of 37 percent in the top subplot.

Table 4.1. Mean Δ percent bermudagrass cover for inter-mowing period one (n=3).

Subplot	NH3	H3	NH6	H6	NH9	H9
Top	29	37	-13	7	7	25
Middle	21	22	1	25	0	-4
Bottom	5	11	-5	23	0	3
Mean (n=9)	18_{A}	23_{A}	-6_{B}	18_{A}	2_{AB}	8_{AB}

Inter-mowing period one – 6/7/10 – 7/15/10
Different subscripts for means denote significant differences (α=0.05)

Bermudagrass cover was affected negatively by the second mowing on 7/15/10 as indicated by Table 4.2 which reports mean Δ percent bermudagrass cover for inter-mowing period 2. Four of the 18 means are negative values indicating an overall decrease in Δ percent bermudagrass cover for the second inter-mowing period, 7/15/10 and 9/9/10, which was a period of drought. Subsequently, not much leaf mass was put on by the bermudagrass stolons during inter-mowing period 2.

Table 4.2. Mean Δ percent bermudagrass cover for inter-mowing period two (n=3).

Subplot	NH3	H3	NH6	H6	NH9	H9
Top	12	-14	-9	-6	1	-5
Middle	-1	-9	-7	-6	-1	-11
Bottom	2	-12	-1	-20	0	-9
Mean (n=9)	4_{A}	-12_{A}	-6_{A}	-11_{A}	0_{A}	-8_{A}

Inter-mowing period two – 7/15/10 – 9/9/10
Different subscripts for means denote significant differences (α=0.05)

Table 4.3 shows the bermudagrass regrowth values from the third mow (9/9/10) until the end of the study (10/12/10). All treatments produced an increase in Δ percent bermudagrass cover for each subplot except the NH9 treatment (top subplot) which displayed a Δ percent bermudagrass cover of negative two percent. Similar to the results from inter-mowing period 1, the H3 treatment produced the largest mean Δ percent bermudagrass cover (35 percent, top subplot).

Table 4.3. Mean Δ percent bermudagrass cover for inter-mowing period three (n=3).

Subplot	NH3	H3	NH6	H6	NH9	H9
Top	29	35	6	15	-2	10
Middle	15	20	13	21	1	5
Bottom	11	4	3	13	1	7
Mean (n=9)	18_{A}	20_{A}	7_{AB}	16_{A}	0_{B}	7_{AB}

Inter-mowing period three – 9/9/10 – 10/12/10
Different subscripts for means denote significant differences (α=0.05)

In addition the Δ percent bermudagrass cover values for all three inter-mowing periods were analyzed as one dataset. Significant differences were found in Δ percent bermudagrass cover between the mowing heights (P=0.0043). As seen below in Table 4.4, the 7.6 cm (3 in) mowing height treatment had a significantly higher short term bermudagrass regrowth than the other two mowing height treatments. These results provide insight on short term response due to mowing height indicating that bermudagrass had the greatest regrowth from a 7.6 cm mowing height.

Table 4.4. Mean Δ percent bermudagrass cover by mowing height for all inter-mowing periods analyzed as one data set.

Mow Height	N	Initial mean % berm. cover	Final mean % berm. cover	Mean Δ % berm. cover
7.6 cm	54	20	32	12.0_A
15.2 cm	54	35	38	3.3_B
22.9 cm	54	34	36	1.7_B

Different subscripts for means denote significant differences (α=0.05)

4.1.2 *Mowing Height - Long Term Analysis*

To test the seasonal response of mowing height on Δ bermudagrass percent cover, the first measurement of percent bermudagrass cover taken on May 17, 2010 was subtracted from the last percent bermudagrass cover measurement taken on October 12, 2010. The calculated values represented average Δ percent bermudagrass cover for each treatment, from the beginning of the study until the end (Table 4.5).

Table 4.5. Mean initial (5/17/10) and final (10/12/10) total percent bermudagrass cover values by treatment and subplot location (n=3).

Mow ht.	7.6 cm				15.2 cm				22.9 cm			
TRT	**NH3**		**H3**		**NH6**		**H6**		**NH9**		**H9**	
Subplot Location	**Init**	**Fin**	**Init**	**Fin**	**Init**	**Fin**	**Init**	**Fin**	**Init**	**Fin**	**Init**	**Fin**
Top	75	45	48	57	23	29	63	88	79	82	46	46
Middle	39	25	33	29	30	41	33	48	42	34	24	20
Bottom	17	12	12	9	7	4	14	34	15	4	26	17
Mean	44	27	31	32	20	25	37	57	45	40	32	28

Significant differences in Δ percent bermudagrass cover were found between the mowing height treatments (P=0.0019) across the entire growing season. As Table 4.6 indicates, the 15.2 cm (6 in) mowing height had a significantly higher Δ percent bermudagrass cover from the beginning to the end of the study. This quantitative result confirmed what was observed at the project site and provides evidence that the 15.2 cm mowing height used by ALDOT is the most appropriate of those tested.

Table 4.6. Mean Δ percent bermudagrass cover for mowing height over the entire study.

Mow Height	N	Initial mean % berm. cover	Final mean % berm. cover	Mean Δ % berm. cover
7.6 cm	18	37	29	-7.9_B
15.2 cm	18	28	41	12.4_A
22.9 cm	18	39	34	-3.6_B

Different subscripts for means denote significant differences (α=0.05)

4.1.3 *Mowing Height Discussion*

During inter-mowing period two (7/15/10 – 9/9/10) bermudagrass regrowth decreased as measured by Δ percent bermudagrass cover. During this period in the middle of the summer there was only 51 mm rainfall accumulated, compared to average rainfall for the area of 246 mm for the months of July and August (World Climate, 1996-2008). Bermudagrass develops into a semi-dormant state during drought and does not put on much new growth during periods of drought (Duble, 2011). Mowing plant material during a period of slow growth such as drought explains why the percent bermudagrass cover did not increase during inter-mowing period two.

For the short term analysis, the 7.6 cm (3 in) mowing treatment was found to significantly increase mean Δ percent bermudagrass cover when results from all treatments and three inter-mowing periods were analyzed together (Table 4.4, n=54). From field observation the 7.6 cm mowing height appeared to yield significantly higher bermudagrass regrowth in the short term as a result of the extreme decrease in foliage that occurred after this close (7.6 cm) mowing. At the end of the season however, the final percent bermudagrass cover was slightly lower than the initial. For all 7.6 cm (3 in) mowing height treatments the average percent bermudagrass cover (initial to final, 5/17/10 – 10/12/10) for the top, middle, and bottom subplots was 61 to 51 percent, 36 to 27 percent, and 15 to 11 percent, respectively. Although these pairs of values indicate a decrease in total percent bermudagrass cover in all subplots over the entire growing season there were no significant long-term difference in the 7.6 cm (3 in) treatment Δ percent bermudagrass cover.

Rather, it was the 15.2 cm (6 in) mowing height that produced positive significant differences in mean Δ percent bermudagrass cover during the long term. This result indicates a slower more gradual increase in bermudagrass cover over the study period. Positive changes in percent bermudagrass cover for the 15.2 cm (6 in) treatment were not significant until the analysis was determined for the long term. This long-term significant difference was evident as a gradual increase in Δ percent bermudagrass cover from one mowing period to the next, which resulted in a large change in bermudagrass regrowth from the beginning of the study to the end, as follows. For all 15.2 cm (6 in) mowing height treatments the average percent bermudagrass cover (initial to final, 5/17/10 – 10/12/10) for the top, middle, and bottom subplots was 43 to 59 percent, 32 to 45 percent, and 10 to 19 percent, respectively.

4.1.4 *Herbicide Analysis*

Herbicide was applied as a maintenance technique on three of six treatments (3 treatments x 3 replications x 3 subplots; n=27) to reduce weed competition with the bermudagrass. Analysis of the Δ percent bermudagrass cover data for the short term, i.e.

between mowing dates, indicates that the herbicide application did not have a significant effect on Δ percent bermudagrass cover for all treatments and replications. However, when analyzing the Δ percent bermudagrass cover data for the long term from the beginning to the end of the study, it was found that application of herbicide did have a significant positive effect on bermudagrass regrowth (P-value = 0.0019) (Table 4.7).

Table 4.7. Mean Δ percent bermudagrass cover by herbicide application for entire study (5/17/10 to 10/12/10).

Herbicide Application	N	Initial mean % berm. cover	Final mean % berm. cover	Mean Δ % berm. cover
No-Herb	27	36	30	-5.6_B
Herb	27	33	39	6.3_A

Different subscripts for means denote significant differences (α=0.05)

4.1.5 *Herbicide Discussion*

The application of herbicide to minimize weed competition with the desired species bermudagrass was found to significantly increase mean Δ percent bermudagrass cover compared to no-herbicide from the beginning to end of the study by 6.3 percent (33 percent cover to 39 percent cover). Likely, the application of herbicide increased mean bermudagrass regrowth as intended by decreasing weed competition (ALDOT, 2008). The no-herbicide application treatments yielded a decrease in mean Δ percent bermudagrass cover (Table 4.7) over the long term indicating there was less bermudagrass cover at the end of the study than the beginning (36 percent cover to 31 percent cover). This result directly relates to the problem of poor long term stands of bermudagrass on slopes in Alabama. The 5.6 percent decrease in total bermudagrass cover for the third year stand of bermudagrass will likely continue to decrease without herbicide application for weed competition. A 6 percent cover decrease in total bermudagrass cover per year will decrease a 100 percent cover bermudagrass stand to less than 80 percent, the ALDOT guideline for acceptable cover, in three to four years. The interaction between mowing height and herbicide application was not found to be significant for short term or long term analysis (P-value=0.13 and 0.51, respectively). Had the interaction been significant, it would have indicated that using mowing height and herbicide applications together would significantly increase bermudagrass regrowth as compared to using mowing height and herbicide applications alone.

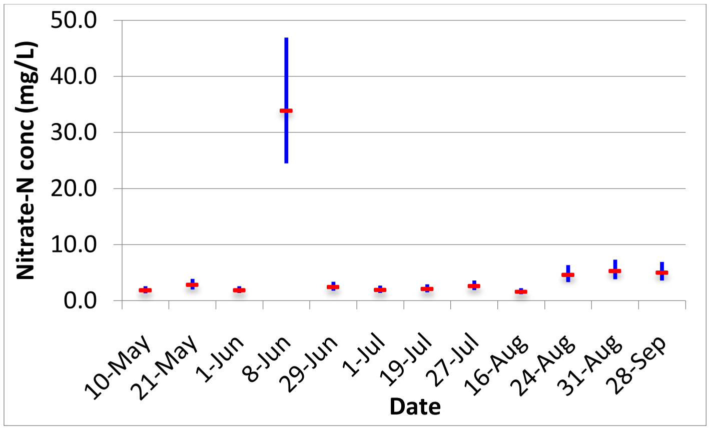
4.2 RUNOFF SAMPLING

4.2.1 *Nutrient Analysis*

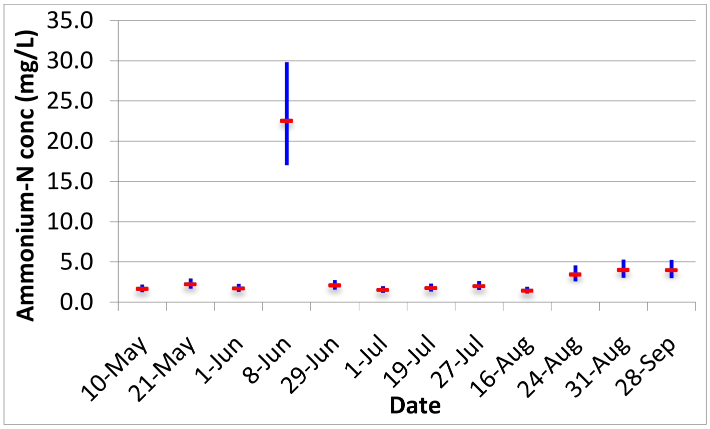
Runoff was captured from the 18 treatment plots and analyzed for differences in mean concentrations for selected nutrients as a response to mowing height and herbicide treatment. Nitrate-N, ammonium-N, and phosphate (PO_4-P) mean concentrations in runoff ranged from 0 to 5.3 mg/L, 0 to 4.0 mg/L, and 0 to 6.5 mg/L, respectively. Peak mean concentration values of 34 and 23 mg/L for nitrate and ammonium, respectively, (Figures 4.2a and b) were found on the June 7, 2010 sampling date directly after the nitrogen application on June 3, 2010. These values are considered high compared to the EPA's limit of 10 mg/L (NO_3-N) for drinking water (USEPA, 2011) and were the result of direct application of nitrogen to the plots and corresponding gutter system, Coshocton wheel, and sampling buckets by an 18.3 meter (60 ft) boom sprayer. The 18.3 meter boom extended directly over the gutter system, Coshocton wheel, and sampling bucket and consequently applied nitrogen to the plots as well as the runoff collection devices. Subsequently, the nitrate and ammonium concentration values in runoff for sampling date June 7, 2010 were excluded from the dataset as in-error outliers. Nitrate-N concentrations above 10 mg/L can cause oxygen depletion in water and what is known as "blue baby syndrome" a potential fatal condition that can cause asphyxiation in children and small farm animals.

There was no application of phosphorus to the treatment plots during this study. Nevertheless, mean PO_4-P concentration in runoff was observed to increased throughout the five-month study period, with the peak mean concentration occurring on the last sampling date (9/28/10). The increase in phosphate concentrations throughout the study suggests that ongoing decomposition of grass clippings during the warmest part of the season returned soluble nutrients to the soil and subsequently in runoff. Peak mean concentration value for phosphate was 6.5 mg/L. There is no regulation on phosphate in drinking water as phosphate is not harmful to humans or animals. However, phosphate concentration levels higher than 0.1 mg/L can lead to eutrophication and oxygen depletion in water bodies.

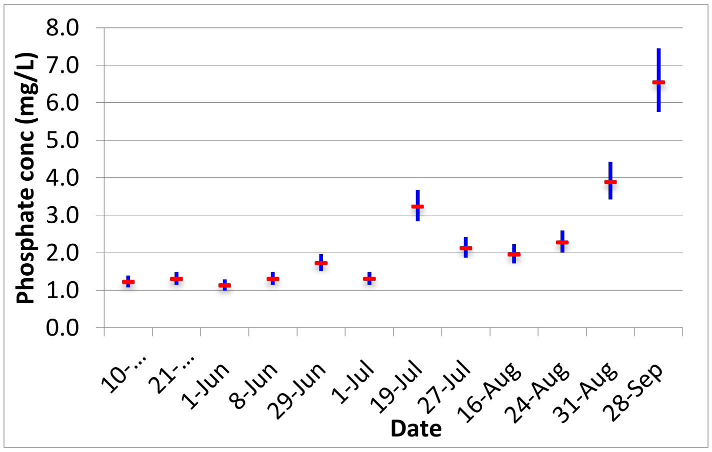
During the last four weeks of the study all inorganic soluble nutrient concentration levels in runoff began to increase (Figure 4.2a, b, and c). The increase in nutrient concentrations can be attributed to the decomposition of grass and weed clippings returning nutrients to the soil. Starbuck (1999) reported that grass clippings benefit turf by returning nutrients and organic matter to the soil during decomposition. Although no leaf analysis was conducted in the present study, Starbuck (1999) and others have reported that grass clippings contain approximately 4 percent nitrogen, 2 percent potassium, and 1 percent phosphorus.



(a) Nitrate-N



(b) Ammonium-N



(c) Phosphate

Figure 4.2. Nitrate-N, Ammonium-N, and Phosphate mean concentration levels with 95% CI for all sampling dates. Spike in Nitrogen concentrations attributed to surface nitrogen fertilizer application immediately prior to sampling.

There were no significant differences in nitrate, ammonium, or phosphate concentrations in runoff between any mowing height or herbicide treatments. P-values for mowing height and herbicide application, respectively were; nitrate (P=0.62 and P=0.46), ammonium (P=0.052 and P=0.38), and phosphate (P=0.24 and P=0.80) indicating no difference between treatments. However, there was an herbicide by height interaction for ammonium found (P=0.03). The no-herbicide 15.2 cm (NH6) treatment had significantly higher ammonium concentrations in runoff than no-herbicide 7.6 and 22.9 cm (NH3 and NH9, respectively) treatments (Figure 4.3). It is possible that certain weeds were present in the no-herbicide 7.6 cm and 22.9 cm treatment plots that more readily utilized ammonium than weeds in the no-herbicide 15.2 cm. However, this hypothesis was unable to be confirmed.

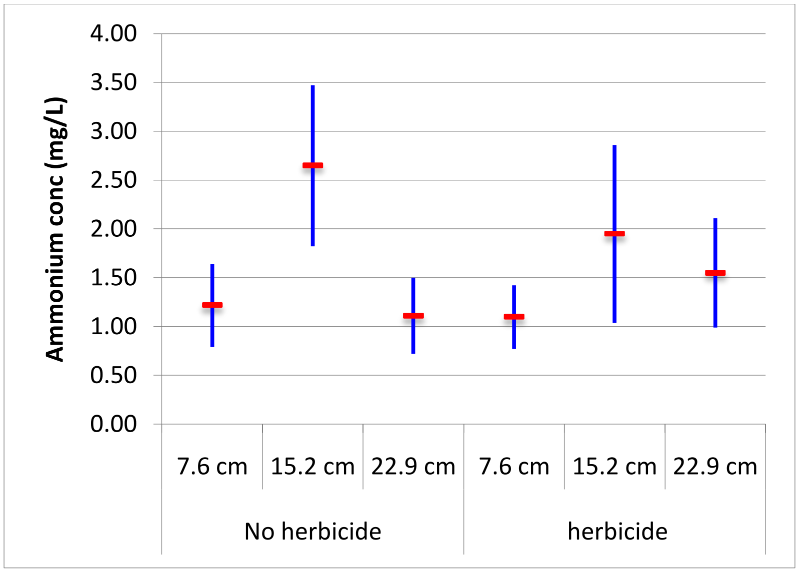


Figure 4.3. Average ammonium runoff concentrations with 95% CI by treatment.

4.2.2 *Turbidity Analysis*

Runoff from the 18 plots was collected and analyzed for turbidity. It was found that there were no significant differences in runoff turbidity values between the different mowing height or herbicide treatments. Average turbidity values for all sampling dates by treatment can be found in Table 4.8. Throughout this study turbidity values rarely exceeded 100 NTUs. The average turbidity value across all treatments and replications throughout the study was 28 NTUs. Therefore, runoff from the plots was not high in sediment content. Perennial vegetative cover has been shown to remove between 50 to 100 percent of total suspended solids from runoff with an average removal of 90 percent (USEPA, 1993). Low turbidity values were expected in this study because areas of exposed soil were few in these third year bermudagrass plots (Table 4.8).

Table 4.8. Mean turbidity values for all sampling dates by treatment (n=36). Corresponding mean percent bare soil and total cover (n=33).

	NH3	H3	NH6	H6	NH9	H9
Mean turbidity (NTU)	29	29	27	23	39	18
Mean %bare soil	1	7	1	2	1	1
Mean % total cover	99	93	99	98	99	99

n=36 – 12 sampling dates x 3 replication plots per sampling date
n=33 – 11 sampling dates x 3 replication plots per sampling date

Turbidity values varied between sampling dates (Figure 4.4) which is expected as turbidity has been known to increase with rainfall depth and intensity (AASHTO, 1982; Hancock, 2009). Rainfall intensity increases sediment transport which increases turbidity values of runoff (Hancock, 2009). As rainfall intensity increases, it is typical for turbidity values in runoff to increase. However, this is most common where there are large areas of disturbed soil and as a result of the high energy of raindrops impacting the soil. Average rainfall intensity for each sampling date but three was determined from tipping bucket data. Data from three storms out of the twelve were excluded due to tipping bucket malfunction. No significant correlation was found in this study between turbidity and recorded rainfall depth or rainfall intensity values for each storm. However, the regression of turbidity with rainfall intensity indicated a positive trend as expected. The correlation coefficient r = 0.40 was not considered significant in this relatively small sample study (Figure 4.5).

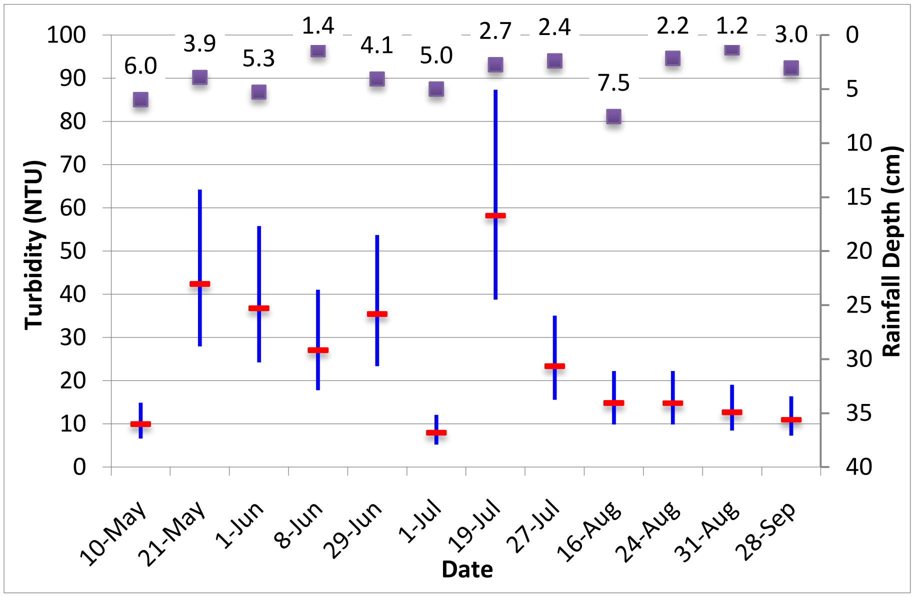


Figure 4.4. Average turbidity values with confidence intervals by sampling date and rainfall depth.

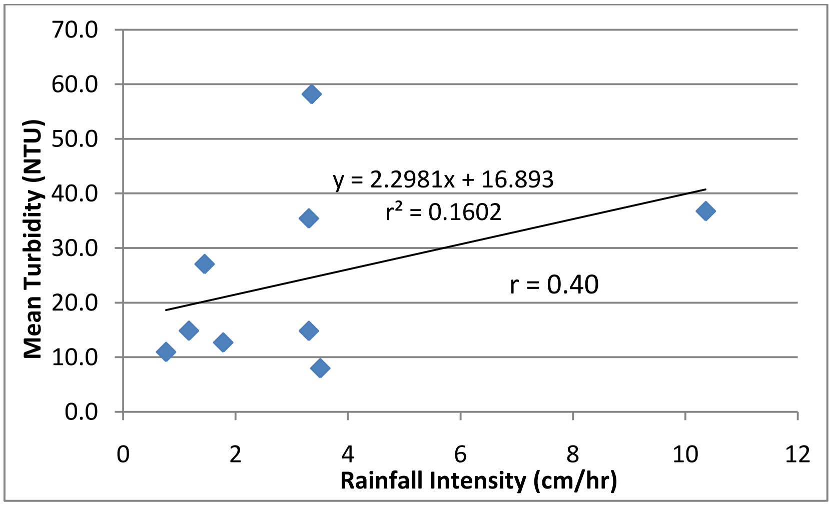
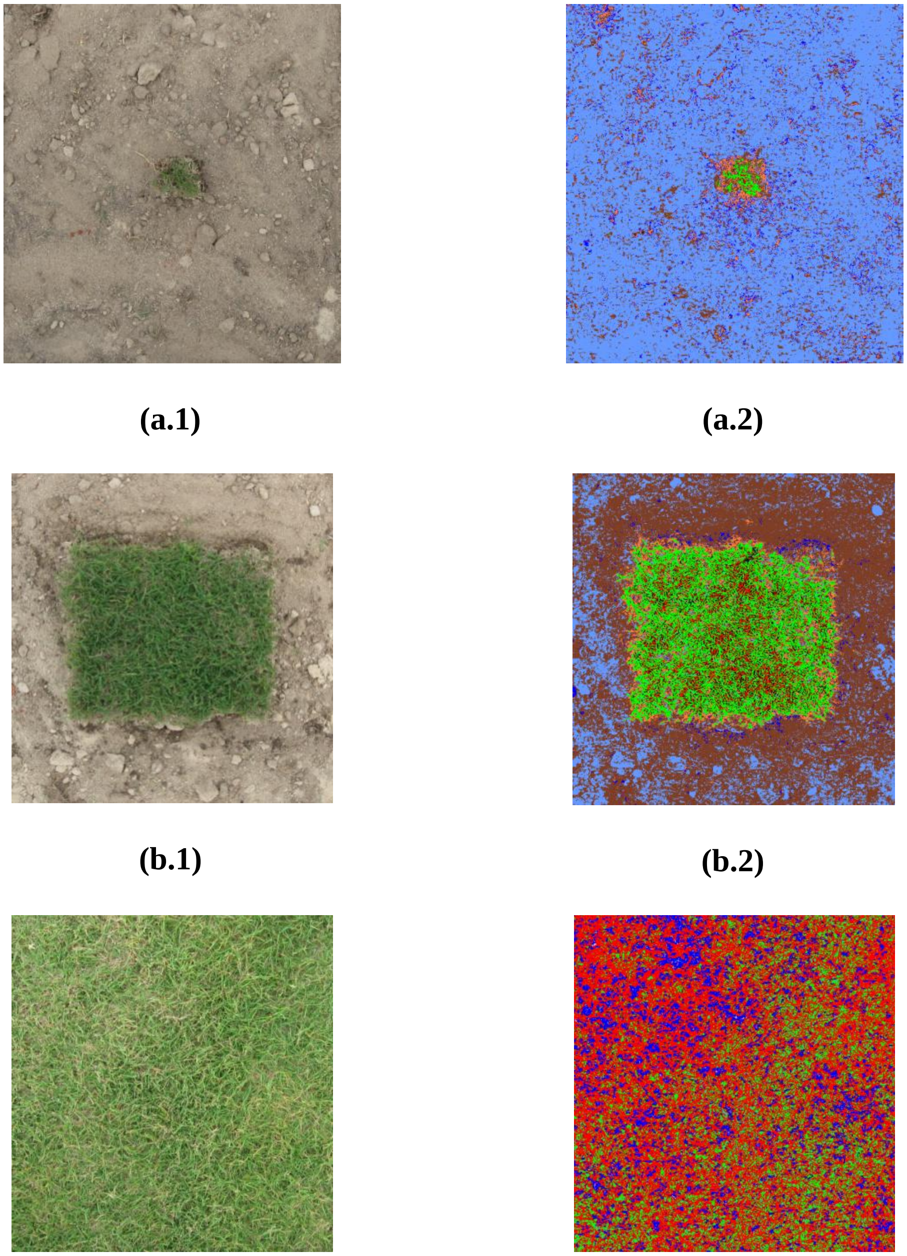


Figure 4.5. Mean rainfall intensity vs. mean turbidity for nine of twelve sampling dates.

4.3 DIGITAL IMAGE ANALYSIS

4.3.1 *DIA Accuracy Assessment*

An accuracy assessment was performed for the DIA software similar to one performed by Richardson et al. (2001). In the study by Richardson et al. (2001), plugs of bermudagrass considered to be 100 percent cover were removed and placed into a bare soil plot of known area. The measured area of bermudagrass plugs divided by the known area of the bare soil plot was calculated to provide a calculated or “actual” cover. The plots were then photographed and analyzed with a DIA method as an assessment to determine the accuracy of the digital method. Similarly, for this assessment study five plugs of bermudagrass sod were measured and placed onto a bare soil plot 48.3 cm x 48.3 cm. Five unique “actual” cover values were obtained using different measured areas of blocked sod. One photograph for each of five “actual” covers ranging from 1 percent cover to 100 percent cover was captured, processed, and analyzed using Hypercube DIA software (Figure 4.6). The average number of pixels in each photograph was 815,099 with an average pixel size equal to 0.0029 cm^2 on the ground. The “actual” cover values were paired with corresponding digital estimate values obtained from Hypercube software (Table 4.9) then graphed as a function of DIA color-derived cover to “actual” cover (Figure 4.6).



(a.1) **(a.2)**

(b.1) **(b.2)**

(c.1) **(c.2)**

Figure 4.6. Photographs a.1 through c.1, show calculated "actual" bermudagrass cover 1, 30, and 100 percent, respectively. Processed DIA images a.2 through c.2 show DIA classification of the same locations.

The first and second columns in Table 4.9 display bermudagrass cover percentages for green and yellow vegetation, respectively. The third column was produced by adding the bermudagrass cover values from the first and second columns and represents all bermudagrass cover. The fourth column shows the field-measured and calculated bermudagrass cover. Cover values from the third and fourth columns are graphed in Figure 4.7.

Table 4.9. Percent cover produced by DIA and calculated "actual" cover from sod.

DIA Green[1] Cover	DIA Yellow[2] Cover	DIA Green[1] + Yellow[2] Cover	Calculated[3] "Actual" Cover
0.3	3.6	3.9	1.0
7.1	11.5	18.6	15.0
21.6	9.7	31.3	30.0
52.8	3.8	56.6	62.0
88.0	11.1	99.1	100.0

[1] Classified as points one and two in DIA.
[2] Classified as points three and four in DIA.
[3] Measured sod area divided by total area of bare soil plot (2333 cm^2).

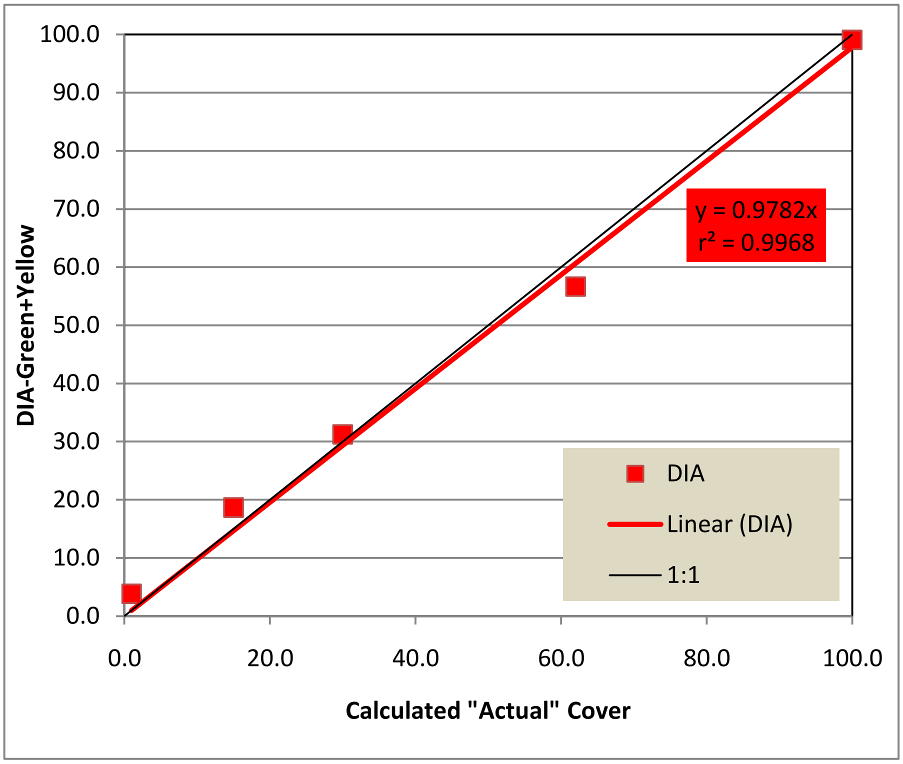


Figure 4.7. Assessment data for DIA versus calculated "actual" cover.

The red line in Figure 4.7 represents a regression line fitted to the paired data. With an intercept set to zero the r^2 value was 0.9968 and the slope of the regression line is nearly one (0.9782) indicating excellent correlation between the DIA estimates of bermudagrass cover and the actual field-measured bermudagrass cover data points. As a result, the DIA data in this small sample control study is considered to be very well correlated to the calculated "actual" cover data. The DIA method is therefore considered to produce an adequate representation of vegetation cover under the conditions tested. Additional replicated field testing would be required to validate these results at the field scale.

Although the data in Figure 4.7 is highly correlated, there is likely some inter-pixel confounding between bermudagrass and soil. Training pixels three and four (light and dark yellow) with training pixels five and six (light and dark brown)may be confused in digital analysis because pixels containing yellow bermudagrass vegetation can resemble pixels of light brown bare soil. It is possible and evident in some DIA photos that bare soil pixels are classified as yellow vegetation and vice versa. Although, inter-pixel confounding would affect results, the effects in this small assessment study appeared minimal.

4.3.2 *DIA Results from Independent TGRU Study*

Although the line transect method is an accepted method to quantify vegetation cover, it has also been reported to overestimate vegetation cover (Richardson et al., 2001; Godinez-Alvarez et al., 2009). From the assessment study performed above, DIA using Hypercube software adequately estimates field verified bermudagrass cover indicating that DIA estimates of total vegetated cover obtained from Hypercube software correlate well with corresponding field measured estimates.

With respect to comparisons between DIA and the standard line transect method, Godinez-Alvarez et al. (2009) report that the line transect method produced significantly higher estimates of vegetation cover than ocular (i.e. including digital) estimates tested. Similarly, Richardson et al. (2001) reported that the line intersect method produced higher estimates of vegetation cover compared to corresponding DIA and ocular methods. The DIA methodology used in this study is found to be quicker and more accurate than the conventional line transect method.

Comparative results between the DIA method and the line transect method collected at TGRU are presented in Figure 4.8. A linear regression fit to the data pairs resulted in a slope equal to 0.98 along with an intercept of -22.7. The slope value of 0.98 indicates that the data follows a trend nearly matching the ideal 1:1 slope but the intercept equal to -22.7 signifies that the Hypercube software used under conditions of this study underestimates vegetation cover by 23 percent when compared to the line transect method. An r^2 value equal to 0.56 indicates that only 56 percent of the variability in the data can be explained by the model.

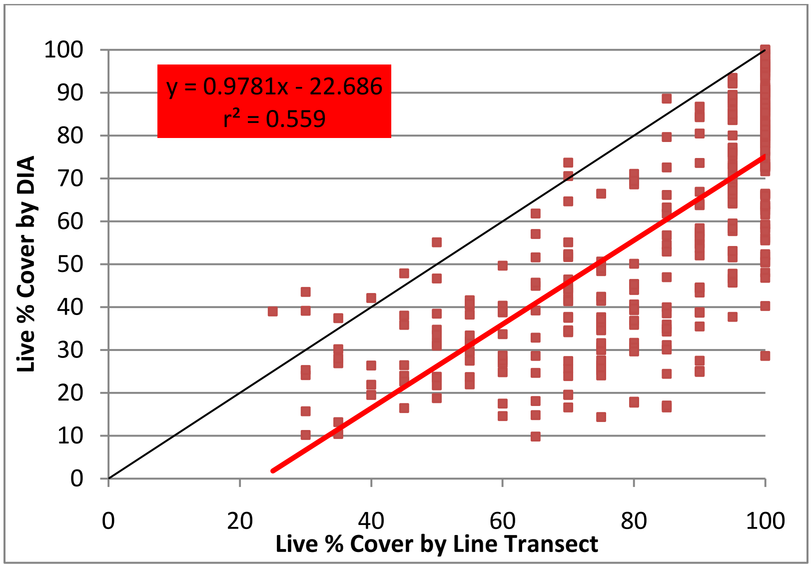


Figure 4.8. Results of line transect data plotted on the x-axis compared to DIA data plotted on the y-axis.

With an r^2 value from the DIA assessment equal to 0.997, (section 4.3.1) most of the variability from the comparative data found in Figure 4.8 appears to come from variability in the line transect method data. Relatively high observer variability and subjectivity compared to DIA methodology are likely the causes of most data variability. However some minimal variability, assumed from the assessment study, also comes from potential inter-pixel confounding discussed earlier. One other major limitation of the DIA method is that it cannot separate different plant species. It appears based on observation that the DIA method performs more accurately on initially established stands of vegetation due to the higher color contrast between pixel colors (green vs. yellow vs. brown pixels).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Part I of this research thesis focused on the agronomic effectiveness of mowing height and herbicide application on the regrowth of a third year stand of common bermudagrass as measured by Δ percent cover. Also evaluated from an environmental perspective were corresponding changes in nitrate, ammonium, and phosphate concentrations in runoff. 18 erosion control plots of third year common bermudagrass located at EVSRC were evaluated under three mowing heights and two herbicide application treatments. Specific objectives were to: (1) evaluate mowing heights of 7.62, 15.24, and 22.86 cm (3, 6, and 9 in) to determine if there was a significantly different response in mean bermudagrass regrowth, (2) determine if the application of herbicide MSMA for weed suppression had a significant effect on mean bermudagrass regrowth, and (3) determine if either mowing height or herbicide application had a significant effect on soluble inorganic nitrogen, phosphorous, ammonium concentration or turbidity in plot runoff.

Part II of the research focused on the use of a digital image analysis (DIA) method to quantify vegetation cover compared to the standard line transect method. Bermudagrass test plots used in part II of the study were independent of plots used in part I. An additional assessment study using a paired set of five bermudagrass/bare soil grids provided documented reference data needed to draw more meaningful conclusions concerning the accuracy of the DIA method. The specific objective of part II therefore was (4) to develop and assess a digital photographic method of cover estimation using a standard field technique for cover estimation of an independent set of bermudagrass cover data.

5.2 BERMUDAGRASS REGROWTH STUDY AT EVSRC (PART I)

5.2.1 Mowing Height and Herbicide Application

The mowing height and herbicide application study on 18 plots at EVSRC began on May 10, 2010 and lasted until October 12, 2010 when the final percent cover data was collected. All plots were mowed to either heights of 7.6 cm, 15.2 cm, and 22.9 cm (3, 6, and 9 in, respectively) three times during of the study (June 7, July 15, and September 9). Following ALDOT maintenance protocol, an herbicide application of MSMA was applied one time (6/2/10) during the study at EVSRC to the 18 designated study plots. Bermudagrass cover was measured on a biweekly basis by the line transect method at designated top, middle, and bottom subplots of each plot. The bermudagrass cover estimates used to calculate Δ percent bermudagrass cover were analyzed as; (1) short term - Δ percent bermudagrass cover for each inter-mowing period as well as all inter-mowing periods grouped as one dataset and (2) long term – Δ percent bermudagrass cover from the beginning of the study until the end. Δ percent bermudagrass cover referred to as bermudagrass regrowth was the main growth response used to determine differences between treatments.

Short term analysis of Δ percent bermudagrass cover indicated that the 7.6 cm (3 in) mowing height produced the highest mean bermudagrass regrowth over all three inter-mowing periods. The 7.6 cm height produced an average increase in total bermudagrass cover of 12.0 percent versus 3.3 percent and 1.7 percent for the 15.2 cm (6 in) and 22.9 cm (9 in) mowing heights, respectively. Herbicide application had no effect on bermudagrass regrowth for the corresponding short term analyses.

Long term analysis of Δ percent bermudagrass cover indicated that the 15.2 cm (6 in) mowing height produced the highest mean bermudagrass regrowth across the growing season. The 15.2 cm height produced an average increase in total bermudagrass cover of 12.4 percent (28% to 40%). The 7.6 cm (3 in) and 22.9 cm (9 in) mowing heights resulted in a decrease in average bermudagrass cover over the season by -7.9 and -3.6 percent cover (37% to 29% and 38% to 34%, respectively). Herbicide application had a significant effect on bermudagrass regrowth for the long term analysis as follows; the application of herbicide significantly increased mean percent bermudagrass cover by 6.3 percent cover (33% to 39%) while no application of herbicide actually resulted in a decrease of bermudagrass cover by 5.6 percent cover (36% to 30%).

The results from objectives 1 and 2 of this research indicate that a 7.6 cm (3 in) mowing height can significantly increase bermudagrass regrowth in the short term while a 15.2 cm (6 in) mowing height significantly increases bermudagrass regrowth for the season (long term). Herbicide application also increased bermudagrass regrowth for the season (long term). Observations in the field indicated that the no-herbicide treatment plots were invaded by crabgrass.

Sustainable establishment of bermudagrass on slopes in Alabama is considered the overall goal of this study. The first two objectives provide valuable information to ALDOT and others interested in maintaining sustained cover on formerly disturbed slopes. Results from this study indicate that a 15.2 cm (6 in) mowing height with herbicide application produced the greatest bermudagrass regrowth in terms of Δ percent cover through the season and on the site studied. Continued use of the current 15.2 cm mowing height with the application of herbicide to minimize weed competition is recommended to obtain the highest sustained mean bermudagrass cover and regrowth. While results from this study support current bermudagrass maintenance recommendations, it is important to note that the study does not evaluate suitability of bermudagrass for long-term cover over all sites in Alabama.

5.2.2 Runoff Sampling

Runoff samples were collected from the 18 treatment plots at EVSRC for 13 different storm sampling dates from 5/10/10 to 9/28/10. 125 mL samples taken back to the laboratory were tested for turbidity and nitrate, ammonium, and phosphate concentration then analyzed for significant differences between treatment means for each constituent.

Average turbidity for all treatments and sampling dates was 28 NTUs. No significant differences were found between treatments for turbidity. Mean turbidity versus rainfall intensity indicated a positive relationship yet poor r value (r = 0.40). Limited correlation between observed turbidity versus rainfall intensity during this study is typical in water variable quality data. Nevertheless, the positive correlation was as expected with increased storm intensities resulting in generally increased turbidities.

Nitrate, ammonium, and phosphate mean concentrations in runoff ranged from 0 to 5.3 mg/L, 0 to 4.0 mg/L, and 0 to 6.5 mg/L, respectively. The peak mean runoff concentration level for phosphate was 6.5 mg/L and occurred on the last sampling date. No phosphorous was applied to the plots.

There were no significant differences between treatments for nitrate and ammonium concentrations in plot runoff although there was a mowing height by herbicide application interaction for ammonium (P=0.0329). The no-herbicide 15.2 cm (6 in) treatment produced significantly higher ammonium concentration in plot runoff than the no-herbicide 7.6 cm and 22.9 cm (3 and 9 in, respectively) treatments. Concentrations of all three inorganic soluble nutrients were observed to increase in runoff concentration levels over the last four sampling dates (8/16/10 – 9/28/10). Increase in concentration levels was attributed to decomposing grass clipping returning soluble nutrients to the soil (Starbuck, 1999).

The results from objective 3 of this research indicate that neither mowing height nor herbicide application had a significant effect on nitrate, ammonium, or phosphate concentrations in runoff from study plots. The herbicide by mowing height interaction for ammonium concentration in runoff that was observed is of little concern since ammonium in solution is relatively harmless to aquatic life and humans.

5.3 DIGITAL IMAGE ANALYSIS STUDY AT TGRU (PART II)

352 digital images from an independent bermudagrass growth study conducted at the TGRU were analyzed using digital image analysis (DIA) then compared to vegetation cover estimates from the standard line transect method. A small assessment study consisting of five imaged and field-measured plot pairs provided reference standards for the comparison accuracy assessment. Although the line transect method is an accepted method it is known to overestimate vegetation cover compared to other methods. Both methods in the assessment study successfully and equally quantified surface features, including vegetation and bare soil. In the longer field study conducted at TGRU over a range of bermudagrass grow-in cover percentages which compared DIA to the line transect method estimates, results similar to Richardson et al. (2001) and Godinez-Alvarez et al. (2009) were found, i.e. the line transect method over estimated vegetation cover compared to the DIA method. Based on the previous assessment of five standardized vegetation plots the line transect estimates were considered responsible for the majority of the variability, over-estimating by 23% cover, and limited correlation with DIA ($r = 0.75$). Results from the limited DIA assessment study in fact indicated that DIA (Hypercube

software) adequately estimated a standardized set of vegetation cover sample grids. For this reason, it is concluded that the majority of the variability in cover estimation methodology is attributed to the line transect method, not DIA. Consequently, results of this study conclude that the DIA method reliably estimates vegetative cover in spite of some inter-pixel confounding between light brown and dark yellow pixels of plant and soil material.

Variability in the paired data is likely due to observer subjectivity during data collection. The results from objective 4 in this research therefore indicate that the DIA method more adequately estimates vegetative cover than the line transect method. However, it was determined that the DIA method is most suitable for initial establishment stands of vegetation due to its ability to recognize the more comparative colors of bare soil versus vegetation. The DIA method cannot identify separate species of vegetation that are the same color.

There are several differences between the line transect and DIA methods. The line transect is highly subjective due to evaluator performance to estimate vegetation coverage whereas the DIA method is relatively less subjective using software to estimate vegetation coverage. Line transect is also more labor intensive than DIA. Although line transect has been repeatedly proven to over-estimate vegetation cover, it is an accepted method of vegetation cover estimation whereas DIA is still in the beginning stages of acceptance. This study demonstrates that DIA can be used to more adequately estimate vegetation cover when compared to the line transect method.

5.4 SUMMARY

Part I of this research was dedicated to determining the effects of mowing height and herbicide application on bermudagrass regrowth as represented by Δ percent bermudagrass cover. Plots located at EVSRC were monitored for Δ percent bermudagrass cover and runoff for turbidity and nutrient concentrations. Treatments were analyzed for significant differences based on each objective. A 7.6 cm (3 in) mowing height produced the highest mean bermudagrass regrowth for the short-term analysis while a 15.2 cm (6 in) mowing height produced the highest mean for the over the entire growing season. Herbicide application significantly increased bermudagrass regrowth over the entire study. Neither mowing height or herbicide application significantly affected nutrient concentrations in runoff

Part II of this research was dedicated to developing and comparing a DIA method to the standard line transect method for estimating vegetative cover. Independent test plots located at the TGRU were utilized for the initial establishment of TifSport bermudagrass. A small assessment for the DIA method was conducted to determine the accuracy of the method. DIA estimates were paired with the corresponding line transect method estimates and correlated. Results concluded that DIA with Hypercube more reliably estimates bermudagrass cover and the line transect method over-estimates bermudagrass cover.

5.5 FUTURE RESEARCH

5.5.1 Bermudagrass Regrowth

The study presented in this thesis dealt specifically with the challenge of sustainable establishment of common bermudagrass on formerly disturbed slopes in Alabama. Effects of both mowing height and herbicide application on common bermudagrass regrowth and water quality were evaluated. Increased sustainability of desired vegetation on formerly disturbed slopes in Alabama using the best maintenance techniques provides many benefits. Improved maintenance techniques generate cost savings as well as fewer negative environmental impacts. It is recommended that further research be conducted in the area of reseeding applications as a supplemental maintenance technique because existing bermudagrass stands of less than 50 percent appear to experience more difficulty reaching an acceptable stand of bermudagrass (80 percent cover as required by ALDOT). Research into common bermudagrass is important because it is consistently used throughout Alabama on disturbed slopes. Also, different varieties of bermudagrass and different cover species should be explored to determine if in fact common bermudagrass is the most suitable for slopes in Alabama compared to other available hybrids or native species. It is recommended that water quality be monitored throughout all areas previously suggested to determine the environmental effects of the maintenance practices.

5.5.2 Digital Image Analysis

DIA is a less labor intensive method of estimating vegetative cover than other ground based estimates. DIA has the potential to provide quicker and more objective estimates of vegetation cover in different areas of research as well as real world applications for land owners who have contracted others to provide a certain percentage of vegetation cover. Further research should explore DIA and conventional ground based methods for quantifying vegetation cover other than the ones explored in this thesis. For example, the line intersect analysis (LIA) aka grid point intercept, which involves superimposing a grid onto the digital image (Karcher et al., 2003) can be evaluated. LIA decreases observer variability and subjectivity by viewing the cover in two dimensions instead of three. Other DIA and ground based methods should be compared to the DIA (Hypercube) method in this study on a wide range of study sites throughout Alabama to further validate that DIA accurately estimates vegetation cover across the range of vegetation species expected in Alabama.

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Appendix A

EVSRC Bermudagrass Regrowth Study Plot Layout with Treatments

A.1 Plot layout with corresponding treamtment.

Plot number[1]	Treatment
1N	NH6
2N	H6
3N	H9
7N	NH6
1W	H9
2W	NH6
3W	H3
4W	NH3
5W	H6
6W	H6
7W	NH9
8W	H3
9W	NH9
10W	H9
11W	NH3
12W	H3
13W	NH9
14W	NH3

[1] The number represents the plot number and the letter represents aspect (i.e. 1N – Plot 1, north facing)

Appendix B

Mean Bermudagrass Regrowth Data

B.1 Mean bermudagrass cover by treatment for the top subplot.

Average Bermudagrass Cover (%) by Treatment (TOP subplot) n=3

TRT	5/17/10	6/1/10	6/14/10	6/29/10	7/14/10	7/27/10	8/10/10	8/24/10	9/7/10	9/21/10	10/12/10
NH3	74.7	86.0	42.7	60.7	72.0	35.3	49.3	50.0	47.3	16.0	44.7
H3	48.0	46.7	38.7	61.3	75.3	52.0	67.3	40.0	38.0	21.3	56.7
NH6	23.3	27.0	31.3	20.0	18.7	27.3	24.7	19.3	18.0	23.3	29.3
H6	62.7	76.7	80.7	88.0	87.3	87.3	88.7	82.7	81.3	73.3	88.0
NH9	78.7	86.0	89.3	90.7	96.0	86.0	86.0	84.0	87.3	84.0	82.0
H9	46.0	54.7	40.0	53.3	64.7	50.7	44.7	56.7	45.3	36.0	46.0

B.2 Mean bermudagrass cover by treatment for the middle subplot.

Average Bermudagrass Cover (%) by Treatment (MIDDLE subplot) n=3

TRT	5/17/10	6/1/10	6/14/10	6/29/10	7/14/10	7/27/10	8/10/10	8/24/10	9/7/10	9/21/10	10/12/10
NH3	39.3	47.3	18.0	28.7	38.7	22.0	21.3	27.3	20.7	10.0	25.3
H3	32.7	40.0	23.3	36.0	45.3	36.7	36.0	27.3	27.3	8.7	28.7
NH6	30.0	40.0	34.7	30.0	35.3	35.3	44.7	28.7	28.0	28.0	41.3
H6	33.3	33.3	32.7	50.7	58.0	44.7	46.0	42.7	38.7	27.3	48.0
NH9	42.0	43.3	38.0	36.0	38.0	34.0	32.7	28.7	33.3	33.3	34.0
H9	24.0	21.3	27.3	28.7	24.7	22.7	20.7	13.3	12.0	14.7	20.0

B.3 Mean bermudagrass cover by treatment for the bottom subplot.

Average Bermudagrass Cover (%) by Treatment (BOTTOM subplot) n=3

TRT	5/17/10	6/1/10	6/14/10	6/29/10	7/14/10	7/27/10	8/10/10	8/24/10	9/7/10	9/21/10	10/12/10
NH3	17.3	10.7	4.0	4.0	8.7	3.3	4.7	2.0	5.3	1.3	12.0
H3	12.0	9.3	8.7	16.7	19.3	18.7	10.0	8.7	6.7	5.3	9.3
NH6	6.7	5.3	5.3	4.0	0.7	2.7	4.0	0.0	2.0	0.7	4.0
H6	14.0	18.7	27.3	35.3	50.0	46.7	38.7	34.7	26.7	20.7	34.0
NH9	15.3	14.0	4.7	7.3	4.7	4.0	1.3	2.7	4.0	2.7	4.0
H9	26.0	22.7	20.7	26.7	24.0	18.0	17.3	10.0	9.3	10.0	17.3

B.4 Mean Δ percent cover by treatment, subplot, and inter-mowing period.

Subplot	Treatment	Mean Δ % berm. Cover (n=3)		
		inter-mow 1[1]	inter-mow 2[2]	inter-mow 3[3]
TOP	NH3	29	12	29
	H3	37	-14	35
	NH6	-13	-9	6
	H6	7	-6	15
	NH9	7	1	-2
	H9	25	-5	10
MIDDLE	NH3	21	-1	15
	H3	22	-9	20
	NH6	1	-7	13
	H6	25	-6	21
	NH9	0	-1	1
	H9	-4	-1	5
BOTTOM	NH3	5	2	11
	H3	11	-12	4
	NH6	-5	-1	3
	H6	23	-20	13
	NH9	0	0	1
	H9	3	-9	7

[1] 6/7/10 – 7/15/10
[2] 7/15/10 – 9/9/10
[3] 9/9/10 – 10/12/10

B.1 Mean Δ percent bermudagrass cover for all inter-mowing periods by subplot location.

Subplot Location	N	Mean Δ % berm. cover
Top	54	9_A
Middle	54	6_A
Bottom	54	2_A

Different subscripts for means denote significant differences ($\alpha=0.05$)

Appendix C

Tipping Bucket Data From EVSRC

C.1 Average rainfall intensity values by date.

Date	AVG Intensity (cm/hr)	# Storms used to calculate AVG = n
10-May		
21-May		
1-Jun	10.36	3
8-Jun	1.45	1
29-Jun	3.30	1
1-Jul	3.51	1
19-Jul	3.35	2
27-Jul		
16-Aug	1.17	2
24-Aug	3.30	2
31-Aug	1.78	1
28-Sep	0.76	3

Appendix D

Manufacturer's Specifications for Experimental Equipment

D.1 Hach Model 2100P Portable Turbidimeter

Measurement Method: Ratio Nephelometric signal (90°) scatter light ratio to transmitted light

Range: 0-1000 NTU with automatic decimal point placement or manual range selection of 0-9.99, 0-99.9 and 0-1000 NTU

Accuracy: ± 2% of reading plus stray light from 0-1000 NTU

Resolution: 0.01 NTU on lowest range

Repeatability: ±1% of reading or 0.01 NTU, whichever is greater (with Gelex standards)

Response Time: 6 seconds for full step change without signal averaging in constant reading mode

Stray Light: <0.02 NTU

Standardization: StablCal® Stabilized Formazin primary standards or Formazin primary standards

Sample Cells: (Height X width) 60.0 X 25 mm (2.36 X 1 in) Borosilicate glass with screw caps, marking band and fill line

Sample Required: 15 mL (0.5 oz.)

Storage Temperature: -40 to 60 °C (-40 to 140 °F) (instrument only)

Operating Temperature: 0 to 50 °C (32 to 122 °F) (instrument only)

Dimensions: 22.2 X 9.5 X 7.9 cm (8.75 X 3.75 X 3.12 in)

InstrumentWeight: 520 kg (1 lb 2.5 oz)

D. 2 Craftsman 55.9 cm (22 in) push lawn mower

Side Discharge Type: Push

Cutting Deck Style: Side discharge

Item Weight: 63.0 lbs.

Cutting positions: 5

Air Filter Type: Foam

Engine Brand: Briggs and Stratton®

Engine Power: 5.5 torque rating (158 cc)

Propulsion Type: Push

Lubrication System: Splash

Fuel Capacity: 1 qt.

Deck Cut Width: 22 in.

Cutting Range: 1 3/8 to 3 ½ in.

D. 3 Canon *PowerShot* A590lS

Make: Canon

Model: A590IS

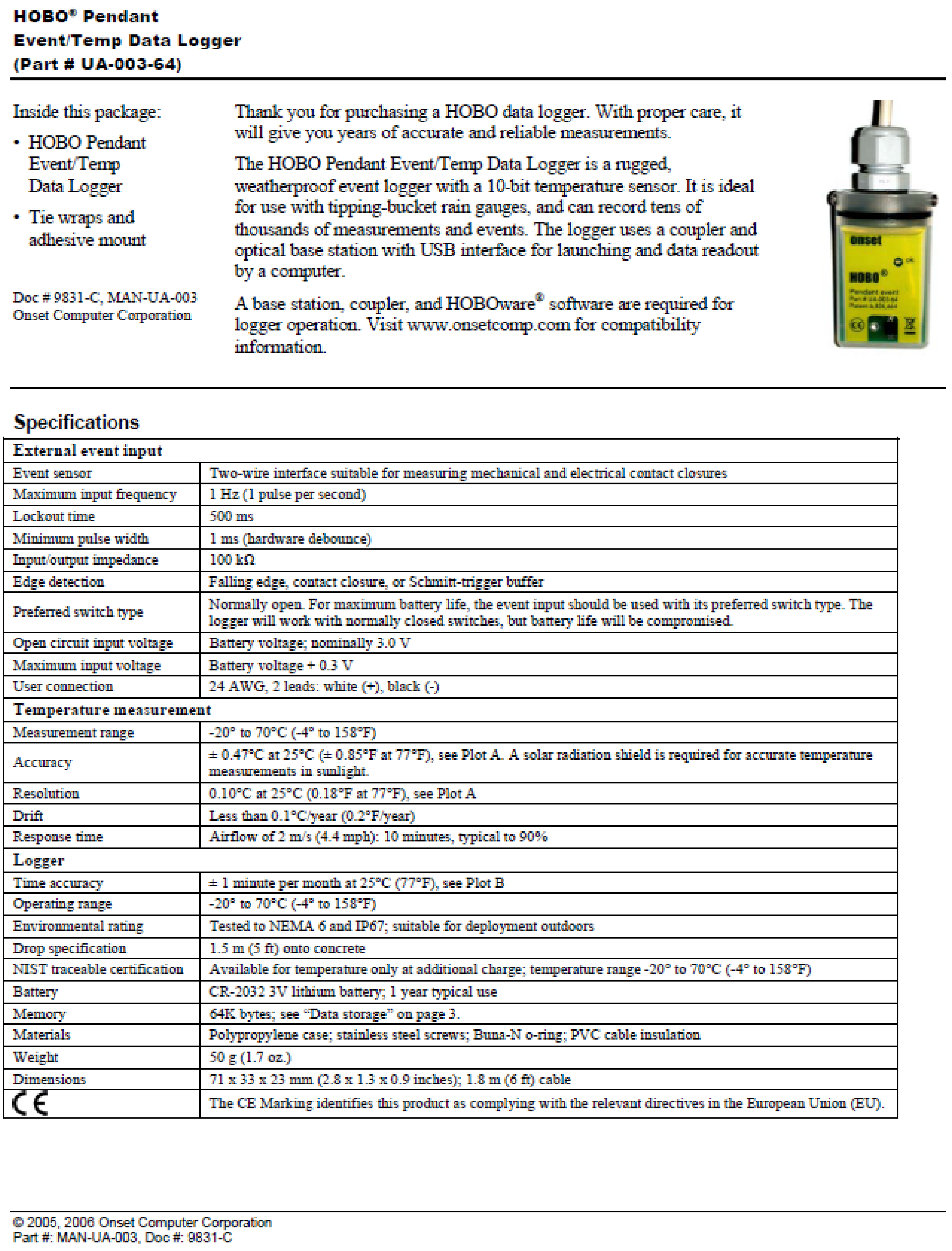
Resolution: 8.0 Megapixel

Optical Sensor Type: CCD

Image Stabilizer: Optical

Optical Zoom: 4x

D.4 HOBO® Pendant Event/Temp Data Logger



HOBO® Pendant
Event/Temp Data Logger
(Part # UA-003-64)

Inside this package:

- HOBO Pendant Event/Temp Data Logger
- Tie wraps and adhesive mount

Doc # 9831-C, MAN-UA-003
Onset Computer Corporation

Thank you for purchasing a HOBO data logger. With proper care, it will give you years of accurate and reliable measurements.

The HOBO Pendant Event/Temp Data Logger is a rugged, weatherproof event logger with a 10-bit temperature sensor. It is ideal for use with tipping-bucket rain gauges, and can record tens of thousands of measurements and events. The logger uses a coupler and optical base station with USB interface for launching and data readout by a computer.

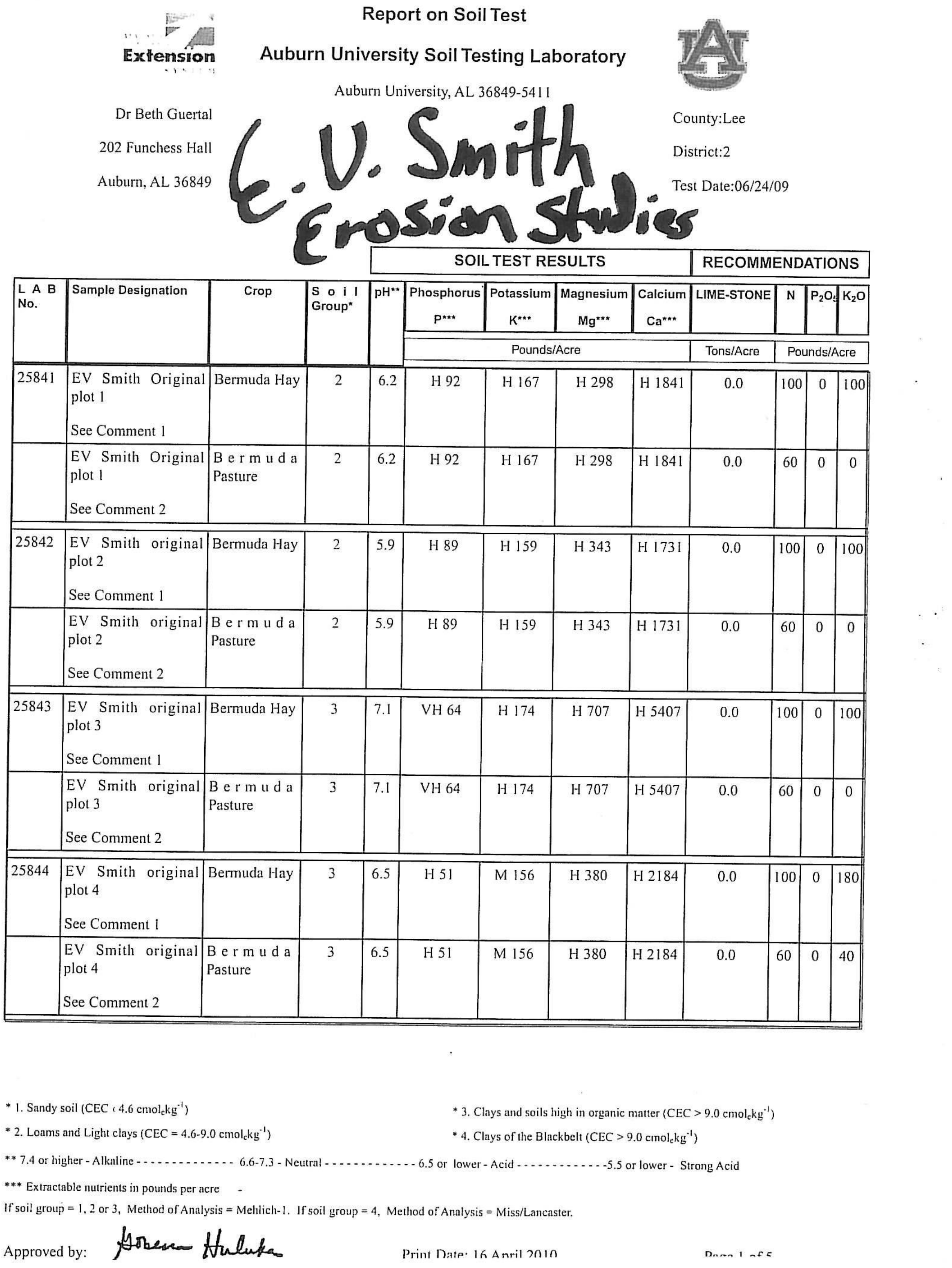
A base station, coupler, and HOBOware® software are required for logger operation. Visit www.onsetcomp.com for compatibility information.

Specifications

External event input	
Event sensor	Two-wire interface suitable for measuring mechanical and electrical contact closures
Maximum input frequency	1 Hz (1 pulse per second)
Lockout time	500 ms
Minimum pulse width	1 ms (hardware debounce)
Input/output impedance	100 kΩ
Edge detection	Falling edge, contact closure, or Schmitt-trigger buffer
Preferred switch type	Normally open. For maximum battery life, the event input should be used with its preferred switch type. The logger will work with normally closed switches, but battery life will be compromised.
Open circuit input voltage	Battery voltage; nominally 3.0 V
Maximum input voltage	Battery voltage + 0.3 V
User connection	24 AWG, 2 leads: white (+), black (-)
Temperature measurement	
Measurement range	-20° to 70°C (-4° to 158°F)
Accuracy	± 0.47°C at 25°C (± 0.85°F at 77°F), see Plot A. A solar radiation shield is required for accurate temperature measurements in sunlight.
Resolution	0.10°C at 25°C (0.18°F at 77°F), see Plot A
Drift	Less than 0.1°C/year (0.2°F/year)
Response time	Airflow of 2 m/s (4.4 mph): 10 minutes, typical to 90%
Logger	
Time accuracy	± 1 minute per month at 25°C (77°F), see Plot B
Operating range	-20° to 70°C (-4° to 158°F)
Environmental rating	Tested to NEMA 6 and IP67; suitable for deployment outdoors
Drop specification	1.5 m (5 ft) onto concrete
NIST traceable certification	Available for temperature only at additional charge; temperature range -20° to 70°C (-4° to 158°F)
Battery	CR-2032 3V lithium battery; 1 year typical use
Memory	64K bytes; see "Data storage" on page 3.
Materials	Polypropylene case; stainless steel screws; Buna-N o-ring; PVC cable insulation
Weight	50 g (1.7 oz.)
Dimensions	71 x 33 x 23 mm (2.8 x 1.3 x 0.9 inches); 1.8 m (6 ft) cable
CE	The CE Marking identifies this product as complying with the relevant directives in the European Union (EU).

Part #: MAN-UA-003, Doc #: 9831-C

D.5 E.V. Smith Soil Test Results Page 1 of 4



Extension

Report on Soil Test

Auburn University Soil Testing Laboratory

Auburn University, AL 36849-5411

Dr Beth Guertal
202 Funchess Hall
Auburn, AL 36849

E. V. Smith
Erosion Studies

County:Lee
District:2
Test Date:06/24/09

LAB No.	Sample Designation	Crop	Soil Group*	pH**	SOIL TEST RESULTS				RECOMMENDATIONS			
					Phosphorus P***	Potassium K***	Magnesium Mg***	Calcium Ca***	LIME-STONE	N	P_2O_5	K_2O
					Pounds/Acre				Tons/Acre	Pounds/Acre		
25841	EV Smith Original plot 1 See Comment 1	Bermuda Hay	2	6.2	H 92	H 167	H 298	H 1841	0.0	100	0	100
	EV Smith Original plot 1 See Comment 2	Bermuda Pasture	2	6.2	H 92	H 167	H 298	H 1841	0.0	60	0	0
25842	EV Smith original plot 2 See Comment 1	Bermuda Hay	2	5.9	H 89	H 159	H 343	H 1731	0.0	100	0	100
	EV Smith original plot 2 See Comment 2	Bermuda Pasture	2	5.9	H 89	H 159	H 343	H 1731	0.0	60	0	0
25843	EV Smith original plot 3 See Comment 1	Bermuda Hay	3	7.1	VH 64	H 174	H 707	H 5407	0.0	100	0	100
	EV Smith original plot 3 See Comment 2	Bermuda Pasture	3	7.1	VH 64	H 174	H 707	H 5407	0.0	60	0	0
25844	EV Smith original plot 4 See Comment 1	Bermuda Hay	3	6.5	H 51	M 156	H 380	H 2184	0.0	100	0	180
	EV Smith original plot 4 See Comment 2	Bermuda Pasture	3	6.5	H 51	M 156	H 380	H 2184	0.0	60	0	40

* 1. Sandy soil (CEC < 4.6 $\text{cmol}_c\text{kg}^{-1}$)

* 2. Loams and Light clays (CEC = 4.6-9.0 $\text{cmol}_c\text{kg}^{-1}$)

* 3. Clays and soils high in organic matter (CEC > 9.0 $\text{cmol}_c\text{kg}^{-1}$)

* 4. Clays of the Blackbelt (CEC > 9.0 $\text{cmol}_c\text{kg}^{-1}$)

** 7.4 or higher - Alkaline - - - - - - - - - - - - - - 6.6-7.3 - Neutral - - - - - - - - - - - - - 6.5 or lower - Acid - - - - - - - - - - - - -5.5 or lower - Strong Acid

*** Extractable nutrients in pounds per acre -

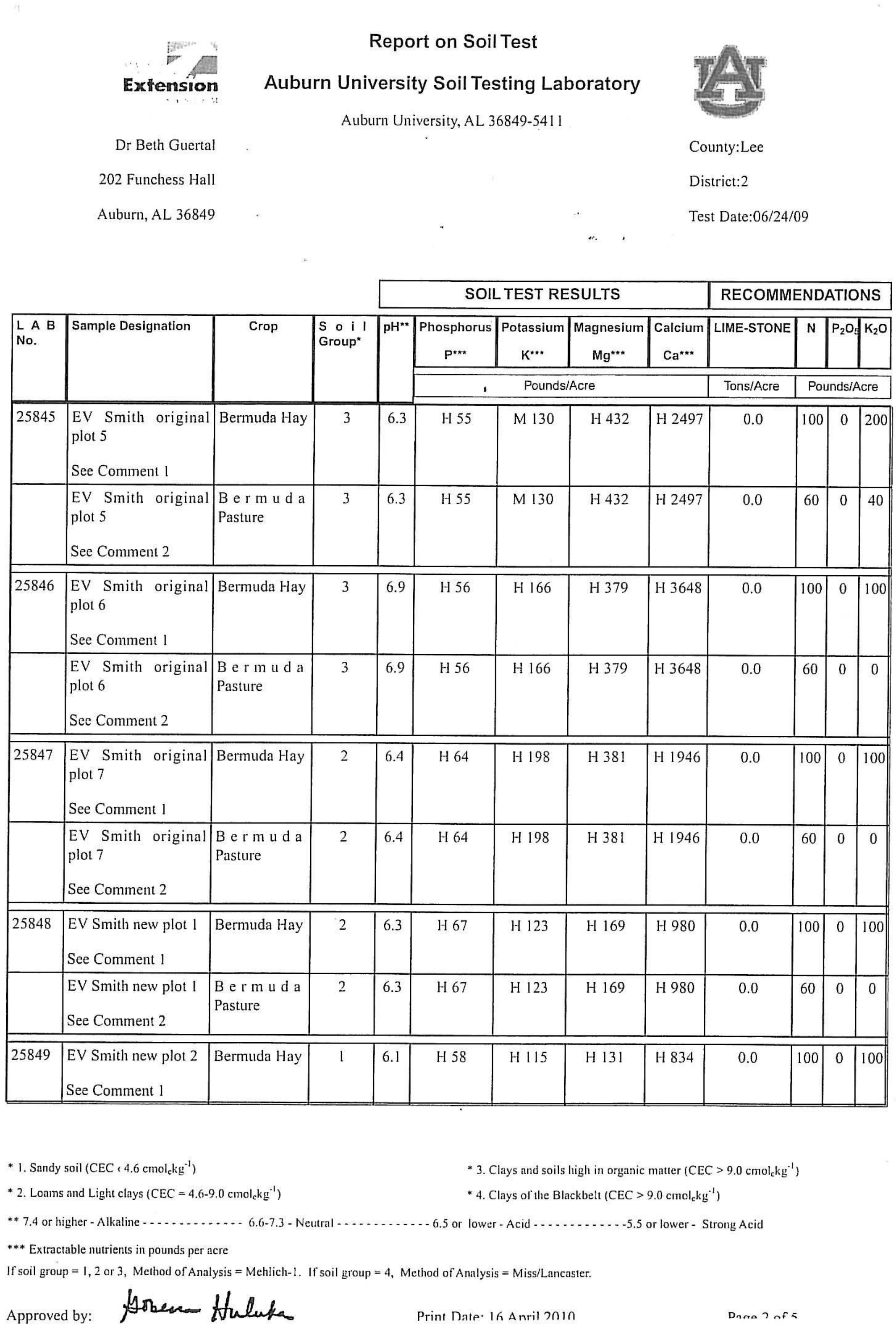
If soil group = 1, 2 or 3, Method of Analysis = Mehlich-1. If soil group = 4, Method of Analysis = Miss/Lancaster.

Approved by: Gobena Huluka

Print Date: 16 April 2010

Page 1 of 5

D.6 E.V. Smith Soil Test Results Page 2 of 4



Extension

Report on Soil Test

Auburn University Soil Testing Laboratory

Auburn University, AL 36849-5411

Dr Beth Guertal
202 Funchess Hall
Auburn, AL 36849

County:Lee
District:2
Test Date:06/24/09

				SOIL TEST RESULTS					RECOMMENDATIONS			
LAB No.	Sample Designation	Crop	Soil Group*	pH**	Phosphorus P***	Potassium K***	Magnesium Mg***	Calcium Ca***	LIME-STONE	N	P_2O_5	K_2O
					Pounds/Acre				Tons/Acre	Pounds/Acre		
25845	EV Smith original plot 5 See Comment 1	Bermuda Hay	3	6.3	H 55	M 130	H 432	H 2497	0.0	100	0	200
	EV Smith original plot 5 See Comment 2	Bermuda Pasture	3	6.3	H 55	M 130	H 432	H 2497	0.0	60	0	40
25846	EV Smith original plot 6 See Comment 1	Bermuda Hay	3	6.9	H 56	H 166	H 379	H 3648	0.0	100	0	100
	EV Smith original plot 6 See Comment 2	Bermuda Pasture	3	6.9	H 56	H 166	H 379	H 3648	0.0	60	0	0
25847	EV Smith original plot 7 See Comment 1	Bermuda Hay	2	6.4	H 64	H 198	H 381	H 1946	0.0	100	0	100
	EV Smith original plot 7 See Comment 2	Bermuda Pasture	2	6.4	H 64	H 198	H 381	H 1946	0.0	60	0	0
25848	EV Smith new plot 1 See Comment 1	Bermuda Hay	2	6.3	H 67	H 123	H 169	H 980	0.0	100	0	100
	EV Smith new plot 1 See Comment 2	Bermuda Pasture	2	6.3	H 67	H 123	H 169	H 980	0.0	60	0	0
25849	EV Smith new plot 2 See Comment 1	Bermuda Hay	1	6.1	H 58	H 115	H 131	H 834	0.0	100	0	100

* 1. Sandy soil (CEC ‹ 4.6 $cmol_ckg^{-1}$)

* 2. Loams and Light clays (CEC = 4.6-9.0 $cmol_ckg^{-1}$)

* 3. Clays and soils high in organic matter (CEC > 9.0 $cmol_ckg^{-1}$)

* 4. Clays of the Blackbelt (CEC > 9.0 $cmol_ckg^{-1}$)

** 7.4 or higher - Alkaline - - - - - - - - - - - - - - 6.6-7.3 - Neutral - - - - - - - - - - - - - 6.5 or lower - Acid - - - - - - - - - - - - -5.5 or lower - Strong Acid

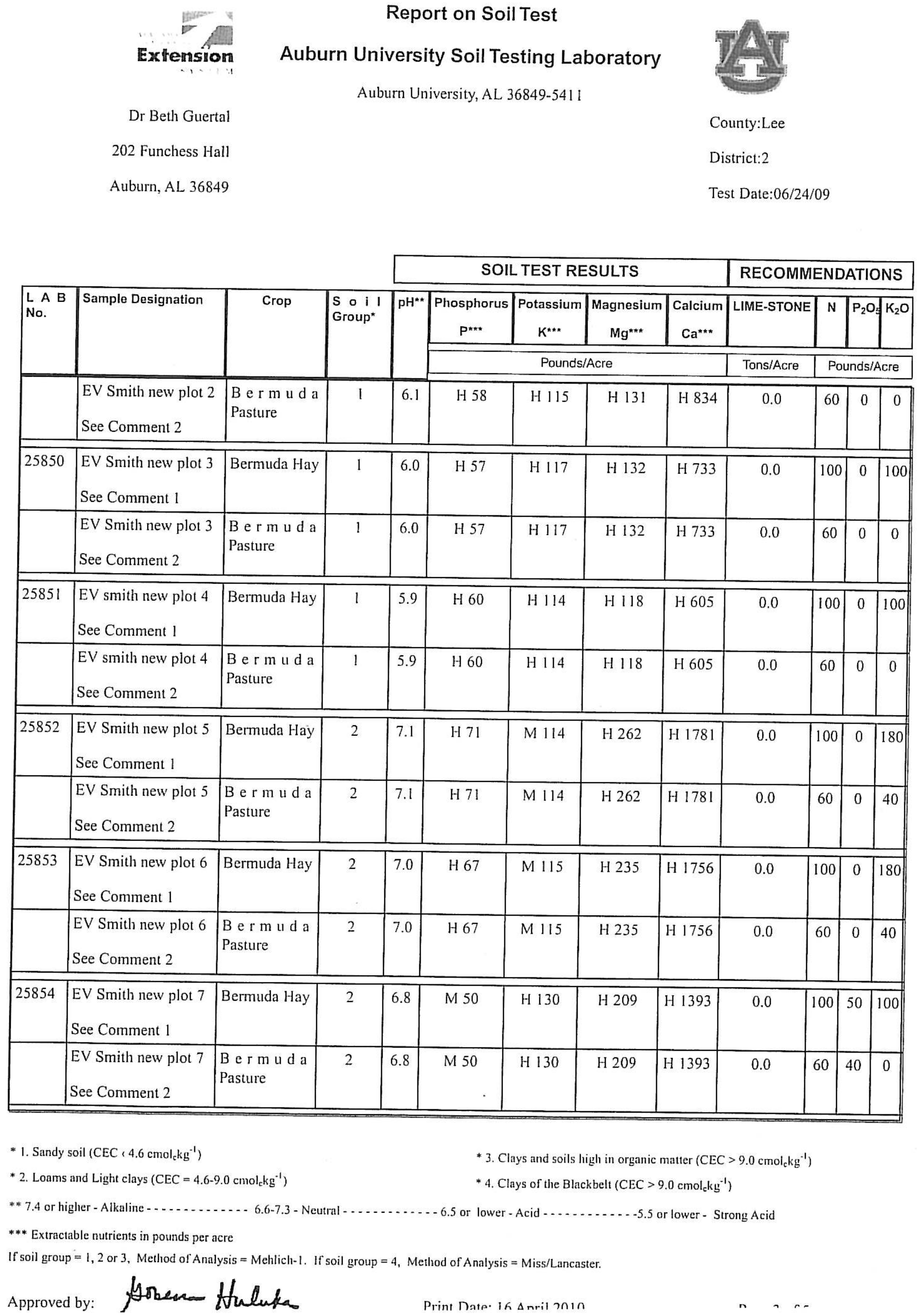
*** Extractable nutrients in pounds per acre

If soil group = 1, 2 or 3, Method of Analysis = Mehlich-1. If soil group = 4, Method of Analysis = Miss/Lancaster.

Approved by: Gobena Huluka

Print Date: 16 April 2010

D.7 E.V. Smith Soil Test Results Page 3 of 4



Extension

Report on Soil Test

Auburn University Soil Testing Laboratory

Auburn University, AL 36849-5411

Dr Beth Guertal
202 Funchess Hall
Auburn, AL 36849

County:Lee
District:2
Test Date:06/24/09

				SOIL TEST RESULTS					RECOMMENDATIONS			
LAB No.	Sample Designation	Crop	Soil Group*	pH**	Phosphorus P***	Potassium K***	Magnesium Mg***	Calcium Ca***	LIME-STONE	N	P_2O_5	K_2O
					Pounds/Acre				Tons/Acre	Pounds/Acre		
	EV Smith new plot 2 See Comment 2	Bermuda Pasture	1	6.1	H 58	H 115	H 131	H 834	0.0	60	0	0
25850	EV Smith new plot 3 See Comment 1	Bermuda Hay	1	6.0	H 57	H 117	H 132	H 733	0.0	100	0	100
	EV Smith new plot 3 See Comment 2	Bermuda Pasture	1	6.0	H 57	H 117	H 132	H 733	0.0	60	0	0
25851	EV smith new plot 4 See Comment 1	Bermuda Hay	1	5.9	H 60	H 114	H 118	H 605	0.0	100	0	100
	EV smith new plot 4 See Comment 2	Bermuda Pasture	1	5.9	H 60	H 114	H 118	H 605	0.0	60	0	0
25852	EV Smith new plot 5 See Comment 1	Bermuda Hay	2	7.1	H 71	M 114	H 262	H 1781	0.0	100	0	180
	EV Smith new plot 5 See Comment 2	Bermuda Pasture	2	7.1	H 71	M 114	H 262	H 1781	0.0	60	0	40
25853	EV Smith new plot 6 See Comment 1	Bermuda Hay	2	7.0	H 67	M 115	H 235	H 1756	0.0	100	0	180
	EV Smith new plot 6 See Comment 2	Bermuda Pasture	2	7.0	H 67	M 115	H 235	H 1756	0.0	60	0	40
25854	EV Smith new plot 7 See Comment 1	Bermuda Hay	2	6.8	M 50	H 130	H 209	H 1393	0.0	100	50	100
	EV Smith new plot 7 See Comment 2	Bermuda Pasture	2	6.8	M 50	H 130	H 209	H 1393	0.0	60	40	0

* 1. Sandy soil (CEC < 4.6 $\mathrm{cmol_c kg^{-1}}$)

* 2. Loams and Light clays (CEC = 4.6-9.0 $\mathrm{cmol_c kg^{-1}}$)

* 3. Clays and soils high in organic matter (CEC > 9.0 $\mathrm{cmol_c kg^{-1}}$)

* 4. Clays of the Blackbelt (CEC > 9.0 $\mathrm{cmol_c kg^{-1}}$)

** 7.4 or higher - Alkaline - - - - - - - - - - - - - - 6.6-7.3 - Neutral - - - - - - - - - - - - - 6.5 or lower - Acid - - - - - - - - - - - - -5.5 or lower - Strong Acid

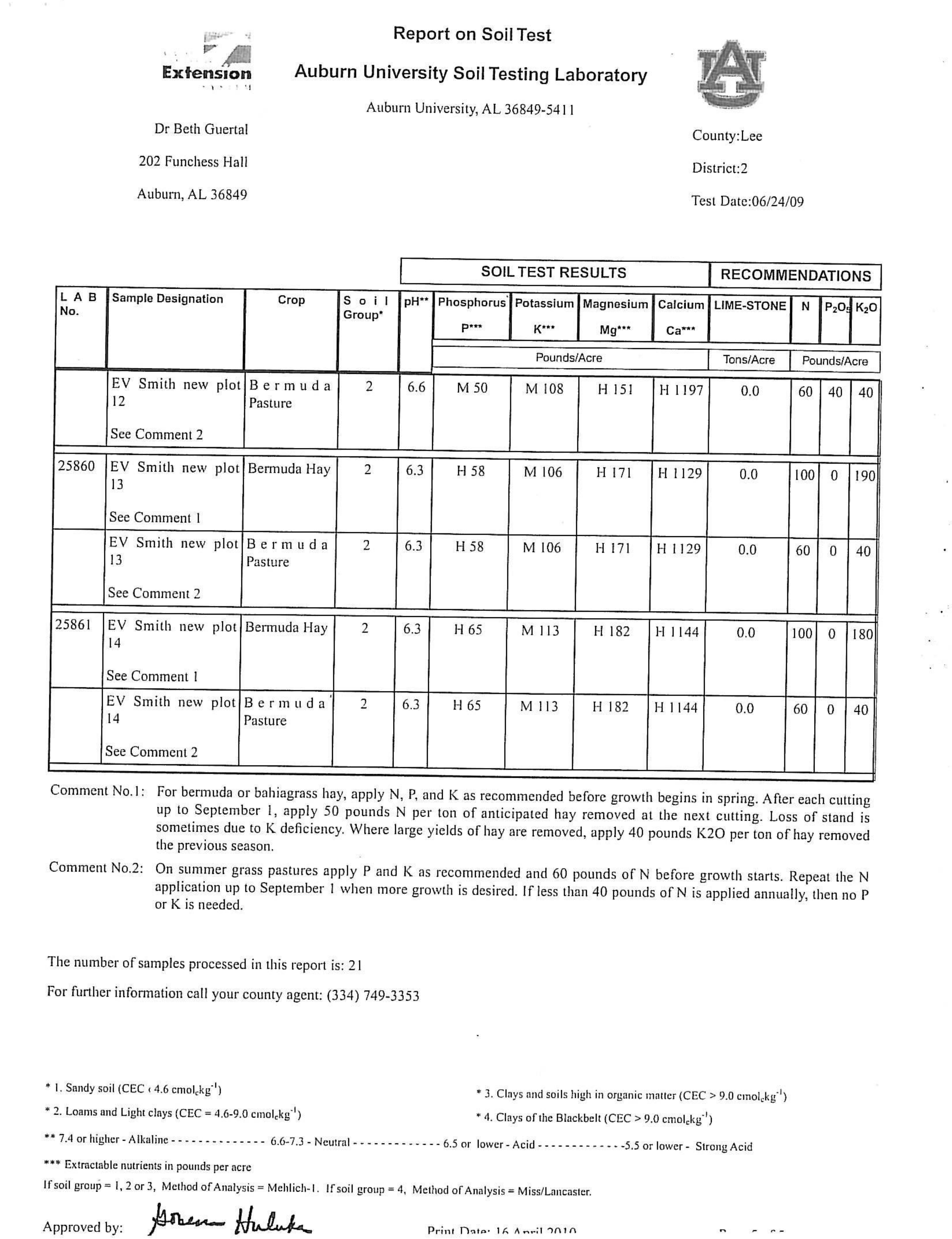
*** Extractable nutrients in pounds per acre

If soil group = 1, 2 or 3, Method of Analysis = Mehlich-1. If soil group = 4, Method of Analysis = Miss/Lancaster.

Approved by: Gobena Huluka

Print Date: 16 April 2010

D.8 E.V. Smith Soil Test Results Page 4 of 4



Extension

Report on Soil Test

Auburn University Soil Testing Laboratory

Auburn University, AL 36849-5411

Dr Beth Guertal
202 Funchess Hall
Auburn, AL 36849

County:Lee
District:2
Test Date:06/24/09

				SOIL TEST RESULTS					RECOMMENDATIONS			
L A B No.	Sample Designation	Crop	Soil Group*	pH**	Phosphorus P***	Potassium K***	Magnesium Mg***	Calcium Ca***	LIME-STONE	N	P_2O_5	K_2O
					Pounds/Acre				Tons/Acre	Pounds/Acre		
	EV Smith new plot 12 See Comment 2	Bermuda Pasture	2	6.6	M 50	M 108	H 151	H 1197	0.0	60	40	40
25860	EV Smith new plot 13 See Comment 1	Bermuda Hay	2	6.3	H 58	M 106	H 171	H 1129	0.0	100	0	190
	EV Smith new plot 13 See Comment 2	Bermuda Pasture	2	6.3	H 58	M 106	H 171	H 1129	0.0	60	0	40
25861	EV Smith new plot 14 See Comment 1	Bermuda Hay	2	6.3	H 65	M 113	H 182	H 1144	0.0	100	0	180
	EV Smith new plot 14 See Comment 2	Bermuda Pasture	2	6.3	H 65	M 113	H 182	H 1144	0.0	60	0	40

Comment No.1: For bermuda or bahiagrass hay, apply N, P, and K as recommended before growth begins in spring. After each cutting up to September 1, apply 50 pounds N per ton of anticipated hay removed at the next cutting. Loss of stand is sometimes due to K deficiency. Where large yields of hay are removed, apply 40 pounds K2O per ton of hay removed the previous season.

Comment No.2: On summer grass pastures apply P and K as recommended and 60 pounds of N before growth starts. Repeat the N application up to September 1 when more growth is desired. If less than 40 pounds of N is applied annually, then no P or K is needed.

The number of samples processed in this report is: 21

For further information call your county agent: (334) 749-3353

* 1. Sandy soil (CEC ‹ 4.6 $cmol_c kg^{-1}$)

* 2. Loams and Light clays (CEC = 4.6-9.0 $cmol_c kg^{-1}$)

* 3. Clays and soils high in organic matter (CEC > 9.0 $cmol_c kg^{-1}$)

* 4. Clays of the Blackbelt (CEC > 9.0 $cmol_c kg^{-1}$)

** 7.4 or higher - Alkaline -------------- 6.6-7.3 - Neutral ------------- 6.5 or lower - Acid ------------ -5.5 or lower - Strong Acid

*** Extractable nutrients in pounds per acre

If soil group = 1, 2 or 3, Method of Analysis = Mehlich-1. If soil group = 4, Method of Analysis = Miss/Lancaster.

Approved by: Gobena Huluka

Print Date: 16 April 2010

Appendix E

Digital Image Analysis Methods and Procedures

E.1 Changing the picture file type from .jpeg files to multiband files.

Changing File Type

1. Locate the file with the original pictures and rename the individual pictures (I use the plot #)
2. Locate the folder with the pictures and copy it by right clicking the folder and choose copy. Paste the copy of the folder in the same location as the original. Now you have two identical sets of the original pictures in .jpeg files.
3. Open Hypercube 32
4. Click “File”, scroll down and click “Open”
5. Locate the copied folder and open the first picture as a .jpeg file
6. Click “File”, scroll down and click “Save As”
7. Leave the same name for the photo (usually the plot #) and save the file type as a “Multiband” file. This will resave the file as a Multiband file that can be analyzed by Hypercube 32.
8. After saving the new file type, close the picture and repeat steps 4 -7.
9. The copied folder will be the new files that can be analyzed by Hypercube 32 and the original folder will be the original folder with the .jpeg files for backup.

E.2 Digital Image Analysis with Hypercube Procedures

Hypercube Instructions

1. Open Hypercube 32
2. Click “File”, scroll down and click “Open”
3. Locate the file to be analyzed
4. Click on the file name and click “Open”
5. Record the number of “Pixels” and “Lines” in the excel spreadsheet. These numbers are located in the upper left hand corner of the “Load” window.
6. Click “Load” and a black and white photo will appear.
7. Click on “Image” at the top of the “Hypercube” window. Scroll down to “Cube Color Composite→” and click “Specific Wave”. A color photo will appear.
8. While holding the “Shift” key, left click two colors for green (Live) vegetation (i.e. light green, dark green)
9. Perform step #8 for brown (Dead) vegetation (i.e. light brown, dark brown)
10. Perform step #8 for bare soil (i.e. light soil, dark soil)
11. Click on “Functions” at the top of the “Hypercube” window. Scroll down and click “Classify”. A “Classify” window will appear. Point #1 will be highlighted and have a neighborhood box in the top left corner.
12. With the point #1 highlighted select 4 other points (totaling 5) around the already highlighted center point. Points slightly darker and slightly lighter than the center point should be selected to achieve a mean color.
13. Perform step #12 for points 2, 3, 4, 5, and 6.
14. Click on the “Options” tab in the “Classify” window.

15. Under the “Classification Match Criteria” section the “Threshold” will be selected. Change the “Threshold” value to “0.12” and click “Ok”. This widens the tolerance for pixels to be classified.
16. Click “Classify” in the “Classify” window. An image with multiple highlighted colors will appear.
17. Click on “Functions” at the top of the “Hypercube” window. Scroll down to “Plot→” “Histogram”→ and click “window”. A small window will appear.
18. Record the values for each Name, number in the excel spreadsheet.
19. View column “R” in the spreadsheet to see if the test was successful (Pass/Fail).
20. View the color photo and the highlighted colors photo to make sure they resemble each other.

Appendix F

Raw Data and SAS Code

F.1 Bermudagrass cover raw data for the top subplot.

Top subplot												
Plot	Trt	5/17/10	6/1/10	6/14/10	6/29/10	7/14/10	7/27/10	8/10/10	8/24/10	9/7/10	9/21/10	10/12/10
1N	NH6	0	4	4	0	0	0	0	0	4	0	8
2N	H6	48	56	82	78	66	90	84	72	66	82	92
3N	H9	4	0	8	6	4	6	8	2	4	6	4
7N	NH6	20	21	54	48	42	70	72	56	48	70	80
1W	H9	80	92	42	76	100	76	54	94	82	52	76
2W	NH6	50	56	36	12	14	12	2	2	2	0	0
3W	H3	36	34	34	44	56	44	56	12	14	14	52
4W	NH3	68	84	40	58	76	34	52	32	36	20	48
5W	H6	76	90	82	92	96	84	90	88	86	70	86
6W	H6	64	84	78	94	100	88	92	88	92	68	86
7W	NH9	66	76	92	96	100	98	94	86	92	94	86
8W	H3	72	72	48	92	96	76	84	80	88	42	72
9W	NH9	84	90	82	88	92	76	82	80	82	80	78
10W	H9	54	72	70	78	90	70	72	74	50	50	58
11W	NH3	80	86	52	50	54	28	32	42	38	6	22
12W	H3	36	34	34	48	74	36	62	28	12	8	46
13W	NH9	86	92	94	88	96	84	82	86	88	78	82
14W	NH3	76	88	36	74	86	44	64	76	68	22	64

Each number represents the % bermudagrass cover for each subplot.

F.2 Bermudagrass cover raw data for the middle subplot.

Middle subplot												
Plot	Trt	5/17/10	6/1/10	6/14/10	6/29/10	7/14/10	7/27/10	8/10/10	8/24/10	9/7/10	9/21/10	10/12/10
1N	NH6	6	12	10	10	10	10	10	6	8	2	12
2N	H6	2	0	10	10	14	14	12	10	4	0	26
3N	H9	4	4	10	16	0	6	6	2	4	4	2
7N	NH6	32	44	60	56	58	66	82	52	50	56	88
1W	H9	28	28	40	38	44	40	30	18	6	14	28
2W	NH6	52	64	34	24	38	30	42	28	26	26	24
3W	H3	38	52	38	44	66	42	50	42	46	14	40
4W	NH3	48	68	28	44	60	22	32	28	32	16	34
5W	H6	48	52	42	70	78	60	62	60	52	40	52
6W	H6	50	48	46	72	82	60	64	58	60	42	66
7W	NH9	70	76	82	74	80	72	68	60	60	64	70
8W	H3	46	58	30	60	70	62	58	40	36	12	42
9W	NH9	30	32	22	22	24	22	20	20	32	26	26
10W	H9	40	32	32	32	30	22	26	20	26	26	30
11W	NH3	26	22	10	6	8	4	6	10	8	6	16
12W	H3	14	10	2	4	0	6	0	0	0	0	4
13W	NH9	26	22	10	12	10	8	10	6	8	10	6
14W	NH3	44	52	16	36	48	40	26	44	22	8	26

Each number represents the % bermudagrass cover for each subplot.

F.3 Bermudagrass cover raw data for the bottom subplot.

Bottom subplot												
Plot	Trt	5/17/10	6/1/10	6/14/10	6/29/10	7/14/10	7/27/10	8/10/10	8/24/10	9/7/10	9/21/10	10/12/10
1N	NH6	0	0	4	6	2	0	4	0	2	0	6
2N	H6	16	22	32	22	20	22	22	16	14	16	30
3N	H9	4	4	4	4	6	6	6	6	2	6	6
7N	NH6	10	8	10	6	0	8	6	0	4	2	6
1W	H9	16	12	14	18	20	12	6	0	6	6	20
2W	NH6	10	8	2	0	0	0	2	0	0	0	0
3W	H3	8	6	4	18	16	32	8	6	4	4	8
4W	NH3	30	22	12	12	26	8	4	6	12	4	10
5W	H6	20	18	26	40	70	54	40	42	26	18	32
6W	H6	6	16	24	44	60	64	54	46	40	28	40
7W	NH9	8	8	0	4	0	0	0	0	0	0	0
8W	H3	28	20	20	30	42	24	20	16	14	10	20
9W	NH9	18	18	14	14	14	12	4	8	12	8	6
10W	H9	58	52	44	58	46	36	40	24	20	18	26
11W	NH3	14	6	0	0	0	0	6	0	4	0	22
12W	H3	0	2	2	2	0	0	2	4	2	2	0
13W	NH9	20	16	0	4	0	0	0	0	0	0	6
14W	NH3	8	4	0	0	0	2	4	0	0	0	4

Each number represents the % bermudagrass cover for each subplot.

F.4 Turbidity raw data

Sample Date:		5/10/2010	5/21/2010	6/1/2010	6/8/2010	6/29/2010	7/1/2010	7/19/2010	7/27/2010	8/16/2010	8/24/2010	8/31/2010	9/28/2010
Rain Gauge (in)		2.35	1.54	2.08	0.54	1.6	1.97	1.08	0.94	2.97	0.85	0.46	1.2
Plot	**Treatment**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**	**Turbidity (NTU)**
4W	NH3	6.23	27.7	11.6	15.5	35	2.77	114	24.6	15.7	19.5	3.23	4
11W	NH3	3.12	58.4	70.5	36.3	41.5	9.25	58	26.7	12.8	13.1	13.6	9.7
14W	NH3	2.95	97.3	76.7	39.5	25.8	7.2	57.9	27.4	17.8	11.3	23.6	9.2
3W	H3	4.23	25	9.97	18	30.2	2.24	234	23.3	19.3	11.3	13.6	10.1
8W	H3	19.8	45.1	35.3	35.8	47.1	19.3	129	50.5	16.4	11.6	9.12	10.3
12W	H3	5.76	30.6	32.3	10.4	26.8	1.82	56.2	7.76	12.2	24.6	6.54	9.4
1N	NH6	34.5	57.8	170	28.3	40.1	10.2	44.5	26.1	12.4	28.8	21	35.4
7N	NH6	15.7	60.5	63.5	26.6	36.4	1.52	31.2	16.7	3.53	14.7	13.2	32.1
2W	NH6	4.54	8.34	10.5	13	15.4	4.08	42.2	11.4	9.1	21.6	18.9	3.9
2N	H6	27.7						47.8	37.9	12.1	26.6	17.5	22.6
5W	H6	10	27.3	14.2	19.2	45.7	9.89	75.3	20.9	28.8	7.32	6.64	8.5
6W	H6	6.97	36.5	37	26.9	33.3	4.35	36.1	15	7.16	3.34	11.9	2.5
7W	NH9	10.7	99.5	158	97.5	60.8	19	75.3	72	32.1	12.1	4.07	5.5
9W	NH9	29.2	105	106	81.7	71.7	30.3	70.9	34.9	17.8	6.17	24.1	3.8
13W	NH9	2	37.7	15.9	13.7	12.8	6.85	29.6	11.5	15.3	14.1	22.3	10.2
3N	H9	15.2	39.6	42.9	17.7	20.2	4.49	20.3	10.3	6.76	15.4	8.38	21
1W	H9	6.06	12.5	9.69	18.6	55.3	13.9	55.2	37.5	19.3	9.74	12.7	14.3
10W	H9	5.07	32.6	21.5	14.6	13	3.09	26.6	8.58	10.1	17.1	4.64	6.5

Turbidity values left blank were excluded due to sample contamination.

F.5 Nitrate-N raw data

Nitrate Analysis - NO_3^--N (mg/L)

Sample Date:		5/10/2010	5/21/2010	6/1/2010	6/8/2010	6/29/2010	7/1/2010	7/19/2010	7/27/2010	8/16/2010	8/24/2010	8/31/2010	9/28/2010
Rain Gauge (in)		2.35	1.54	2.08	0.54	1.6	1.97	1.08	0.94	2.97	0.85	0.46	1.2
Plot	**TRT**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
1N	NH6	4.12	5.96	2.84	126.58	5.19	2.69	3.54	4.45	0.66	6.97	14.72	5.62
2N	H6	1.96	6.96	6.45	132.86	10.96	5.03	4.84	3.38	0.85	3.76	11.56	8.68
3N	H9	0.90	2.47	1.54	69.28	2.57	0.67	1.99	3.48	0.28	2.92	5.19	8.03
7N	NH6	1.48	4.90	3.77	14.38	4.47	0.85	0.64	1.49	1.02	4.21	6.02	9.10
1W	H9	0.78	1.44	0.05	1.82	1.03	0.63	2.82	2.70	1.35	6.33	5.97	6.81
2W	NH6	0.02	1.59	0.23	2.15	0.40	0.38	0.27	3.08	1.40	4.41	3.57	5.29
3W	H3	1.24	1.58	0.20	5.94	0.77	0.23	0.01	1.57	0.64	4.93	3.84	2.55
4W	NH3	0.00	0.54	0.26	3.43	0.67	0.13	2.01	0.84	-0.10	0.69	2.18	1.55
5W	H6	0.24	0.65	0.26	13.24	0.77	0.59	0.25	0.08	0.05	7.28	6.99	2.25
6W	H6	0.04	0.52	0.06	97.53	0.69	0.37	0.31	0.64	-0.13	3.35	5.37	2.32
7W	NH9	0.00	0.61	0.81	50.93	0.73	0.46	0.70	0.31	0.14	6.77	3.63	2.48
8W	H3	2.85	2.55	1.52	38.61	2.41	2.94	0.68	2.40	1.35	4.42	2.51	4.39
9W	NH9	0.46	1.73	0.61	56.52	1.17	1.69	0.18	1.10	0.97	0.79	4.04	2.85
10W	H9	1.82	1.13	0.52	92.82	0.46	0.44	0.52	0.08	0.03	1.75	2.32	2.95
11W	NH3	0.00	0.66	0.37	89.10	0.39	1.23	0.09	1.12	0.46	3.20	4.97	2.72
12W	H3	0.24	1.68	0.41	62.70	0.68	0.34	7.15	2.49	0.90	2.49	1.02	1.47
13W	NH9	1.84	2.17	0.84	29.73	0.66	1.12	1.05	2.01	0.66	2.93	2.86	5.74
14W	NH3	2.19	2.70	1.41	249.62	2.80	1.14	1.26	2.91	2.23	5.19	2.88	6.40

F.6 Ammonium-N raw data

Ammonium Analysis - NH_4^+-N (mg/L)

Sample Date:		5/10/2010	5/21/2010	6/1/2010	6/8/2010	6/29/2010	7/1/2010	7/19/2010	7/27/2010	8/16/2010	8/24/2010	8/31/2010	9/28/2010
Rain Gauge (in)		2.35	1.54	2.08	0.54	1.6	1.97	1.08	0.94	2.97	0.85	0.46	1.2
Plot	**TRT**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
1N	NH6	4.07	4.52	2.82	83.94	4.65	0.90	2.80	3.06	0.39	5.40	10.06	5.49
2N	H6	0.83	3.80	2.46	77.00	6.62	0.98	3.66	2.92	0.22	0.72	9.66	8.29
3N	H9	0.88	1.34	1.37	44.27	1.85	0.38	0.68	2.40	0.38	2.20	4.11	6.50
7N	NH6	1.17	2.79	3.28	10.72	3.91	0.44	0.78	1.22	0.57	2.99	3.93	7.32
1W	H9	0.26	0.84	0.24	1.85	0.84	0.43	2.48	1.80	0.73	4.06	3.77	5.29
2W	NH6	0.21	0.55	0.29	1.73	0.34	0.38	0.55	0.70	1.00	3.35	2.82	4.65
3W	H3	0.36	1.22	0.18	4.08	0.40	0.28	0.32	0.62	0.22	3.73	2.72	2.38
4W	NH3	0.20	0.35	0.14	2.18	0.31	0.24	0.71	0.51	0.20	0.43	1.04	1.33
5W	H6	0.34	0.41	0.24	7.74	0.30	0.44	0.23	0.16	0.22	5.07	5.99	1.59
6W	H6	0.18	0.46	0.29	59.81	0.36	0.36	0.35	0.47	0.15	2.09	3.85	0.75
7W	NH9	0.14	0.41	0.36	26.14	0.41	0.48	0.44	0.28	0.26	4.38	2.72	1.33
8W	H3	0.70	1.51	0.76	23.46	2.09	0.85	0.59	0.65	0.50	2.93	1.74	2.30
9W	NH9	0.24	1.07	0.52	31.97	0.59	0.89	0.19	0.72	0.46	0.42	1.73	2.37
10W	H9	1.66	0.99	0.39	56.02	0.45	0.35	0.37	0.28	0.12	1.59	0.98	1.11
11W	NH3	0.17	0.50	0.41	45.42	0.46	0.52	0.22	0.93	0.28	2.25	3.94	2.22
12W	H3	0.43	1.64	0.35	32.05	0.45	0.36	0.22	0.89	0.68	1.84	0.94	1.34
13W	NH9	0.83	1.42	0.69	35.68	0.71	0.71	1.01	1.11	0.58	2.28	2.51	4.37
14W	NH3	2.04	2.11	1.20	134.56	2.08	0.62	1.07	1.81	1.48	4.04	1.54	4.80

F.7 Phosphate raw data

Phosphate Analysis - PO_4^- - H_2O (mg/L)

Sample Date:		5/10/2010	5/21/2010	6/1/2010	6/8/2010	6/29/2010	7/1/2010	7/19/2010	7/27/2010	8/16/2010	8/24/2010	8/31/2010	9/28/2010
Rain Gauge (in)		2.35	1.54	2.08	0.54	1.6	1.97	1.08	0.94	2.97	0.85	0.46	1.2
Plot	**TRT**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
1N	NH6	0.95	1.24	0.51	0.67	1.11	0.51	1.69	2.57	1.07	1.63	4.00	11.76
2N	H6	0.54	0.73	0.32	0.35	1.71	0.58	2.63	2.01	0.85	1.54	2.19	9.93
3N	H9	0.17	0.32	0.20	0.45	0.39	0.24	1.04	1.20	0.48	0.95	3.44	9.89
7N	NH6	0.20	0.54	0.29	0.32	0.83	0.30	2.32	1.57	0.92	1.69	2.88	12.46
1W	H9	0.04	0.23	0.01	1.49	0.89	0.45	2.63	1.32	0.98	1.82	3.00	5.50
2W	NH6	0.01	0.23	0.07	0.42	0.95	0.33	6.46	1.85	1.97	1.79	4.47	8.73
3W	H3	0.10	0.20	0.00	0.07	1.11	0.18	4.00	3.53	0.42	1.04	2.53	3.51
4W	NH3	0.17	0.20	0.00	0.00	0.95	0.21	8.08	0.79	0.48	1.01	1.85	4.87
5W	H6	0.00	0.07	0.07	0.00	0.42	0.18	1.26	0.63	2.38	1.26	3.24	4.45
6W	H6	0.10	0.00	0.00	0.13	0.45	0.12	0.42	0.57	0.39	0.85	2.31	5.77
7W	NH9	0.10	0.01	0.17	0.20	0.42	0.30	1.54	0.26	0.32	0.98	0.94	2.62
8W	H3	0.32	0.48	0.26	0.32	0.67	0.48	3.75	0.63	0.85	1.16	3.20	3.08
9W	NH9	0.01	0.23	0.10	0.10	0.48	0.30	1.57	0.48	1.41	0.70	2.34	3.16
10W	H9	0.29	0.23	0.20	0.51	0.73	0.42	1.54	0.85	0.92	1.60	3.82	2.81
11W	NH3	0.13	0.20	0.01	0.13	0.36	0.15	1.57	0.73	0.51	1.10	1.99	3.20
12W	H3	0.17	0.20	-0.02	0.10	0.51	0.18	1.60	0.60	1.35	1.54	5.46	6.51
13W	NH9	0.58	0.35	0.13	0.20	0.67	0.39	2.47	1.57	2.35	1.82	4.68	8.07
14W	NH3	0.61	0.45	0.17	0.64	0.91	0.30	2.13	1.32	1.10	1.07	2.38	4.76

F.8 SAS code used for statistical analysis.

```
PROC FORMAT ; VALUE hb 1='Herb' 0='NoHerb';
data m1;
input herb$ ht$ cover;
format herbicide hb. height best5.;
height=substr(ht,1,1);
herbicide=(herb = 'H');
datalines;
NH    3in   -20
NH    3in   -58
NH    3in   -12
H     3in   16
H     3in   0
H     3in   10
NH    6in   8
NH    6in   60
NH    6in   -50
H     6in   44
H     6in   10
H     6in   22
NH    9in   20
NH    9in   -6
NH    9in   -4
H     9in   0
H     9in   -4
H     9in   4
;
run;

proc means data = m1;
   class herbicide height;
   var cover;
   OUTPUT out=means mean=mean std=std stderr=stderr;
run;

PROC GPLOT data=means;
  PLOT mean*height=herbicide; where _type_=3;
RUN;

proc glm data=m1; class herbicide height;
model cover=herbicide height ;
means herbicide   height / tukey;
output out=resid r=resid p=pred;
run;

proc univariate data = resid normal;
   var resid;
   histogram resid / normal;
   qqplot resid / normal (L = 1 mu = est sigma = est);
run;
```