ASSESSING BELOWGROUND BIOMASS CHANGES FOLLOWING LAND MANAGEMENT AND VEHICLE DISTURBANCE

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Agricultural and Biological Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2013

Urbana, Illinois

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ABSTRACT

Military training is destructive by nature and removes vegetation, leading to excess soil degradation if not properly maintained. The Army in particular was interested in incorporating the cumulative effects of military training on vegetation into their land carrying capacity models. An understanding of the impacts and methods to reduce impacts would increase training throughput, minimize costs, and improve training realism. This study is the beginning of an effort to understand the otherwise unknown interactions of military disturbance and land management practices on belowground biomass. Military training effects on belowground biomass, the portion of the plant necessary for recovery, have not been researched exclusively previous to this study.

Belowground biomass is inherently difficult to study because of the need to separate the roots from soil with minimal damage as well as identification of the root biomass to an individual species. In order to efficiently extract roots from soil cores, a new methodology was developed and implemented to reduce cost and obtain more accurate measurements compared to traditional hand washing and pneumatic methods.

This study was done for two years at Fort Riley, Kansas which was comprised of a three by three factorial design with three levels of military impacts and three land management techniques carried out at two site locations with three blocks at each location. The study showed that light trafficking caused a 21% reduction in belowground biomass. Similarly, even with a year of recovery, there was still a 22% reduction in belowground biomass. After two consecutive years of trafficking a 45% reduction in belowground biomass was observed. Land management practices have been researched in the past, but many report conflicting results. This study found fire and mowing to increase belowground biomass compared to the control by 10% and 4%

respectively. The interaction of the two is of chief concern to military land mangers when determining training land carrying capacity and deciding training schedules, management strategies, and allocation of resources for reclamation.

ACKNOWLEDGMENTS

I would like to start by thanking Heidi Howard of the Army Corps of Engineers ERDC-CERL for not only encouraging me to pursue a master's degree but also providing me with the means and guidance to do so. Also a special thanks to Daniel Koch of the Army Corps of Engineers ERDC-CERL for all his help and guidance through graduate school. I would also like to thank the many others who helped with the data collection, processing, and analysis from the Construction Engineering and Research Laboratory (CERL) in Champaign, IL, the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH, the Integrated Training Area Management (ITAM) group at Fort Riley, KS, Kansas State University (KSU) in Manhattan, KS, and the University of Illinois at Urbana-Champaign (UIUC). I would like to especially thank Alan Anderson (CERL), Casey Campbell (CERL), Anne Daine-Owens (CERL), Niels Svendsen (CERL), Tim Cary (CRREL), Dr. Phil Woodford (ITAM), Monte Cales (ITAM), Tony Davis (ITAM), Brandon Lantz (KSU), and Taylor Leahy (UIUC).

Thank you to Dr. Prasanta Kalita (UIUC) for serving as my advisor and understanding my situation of working while going to graduate school. I greatly appreciate the hours of meetings Dr. George Gertner (UIUC/CERL) had with me during exploratory analysis, model selection, and graph development; I thank you for serving on my committee too. Thank you to Dr. Richard Cooke (UIUC) for serving on my committee as well.

Funding and support for this work was provided by ERDC-CERL under the Army 6.2 A896 program and as a part of the Optimal Allocation of Training Lands (OPAL) Work Package.

Lastly, I want to thank my parents, family, and close friend for their encouragement and support.

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CHAPTER 1: INTRODUCTION

Military exercises demand vast resources to effectively train soldiers to accomplish their mission. Army Regulation 350-19 outlines the responsibilities and assigns policies for maximizing the capability, availability, and accessibility of Army training lands through the Sustainable Range Program (SRP). The Integrated Training Area Management (ITAM), a part of SRP, allows the Army to manage and maintain training lands by incorporating requirements of missions and environmental conservation to prescribe appropriate land management practices (U.S. Department of the Army, 2005).

The destructive nature of military training removes vegetation and can lead to soil degradation overtime without proper management. Vegetation has a significant influence on ground cover, mechanical and hydrological soil properties. These properties dominate important processes like vegetation community dynamics, soil erosion, vehicle mobility, and overall safety of training lands. The Army is interested in understanding cumulative effects of training events and land management practices on biomass to improve training land quality. More importantly, the Army intends to include vegetation in current land carrying capacity models in order to quantify the beneficial effects of belowground biomass on soil strength. The overarching goal of the military is to increase training throughput, minimize training land management costs, and improve training realism through proper land management.

Knowledge of belowground biomass rooting structure is crucial in order to understand numerous biological and physical processes in soil and vegetation interactions. Rooting structure, more specifically root hairs, provide a method for plants to uptake nutrients and soil moisture (Gibson, 2009). Additionally, belowground biomass stabilizes soil structure increasing soil traffickability and shear strength while reducing erosion (Frei, 2009; Steichen et al., 2008;

Fan and Su, 2008). Roots influence aggregate formation through secretion of solidifying compounds but also cause wetting and drying cycles and provide a food source for microflora and fauna (Angers and Caron 1998). However, studying belowground biomass is inherently a difficult task as the subject in question is interwoven in the soil profile. Unlike research involving aboveground biomass, the belowground portion must be separated from the soil. Collection and processing of root samples often requires specialized equipment and supplies adding a significant burden to a research project.

To begin understanding the effects of training events and land management practices on belowground biomass, a new methodology of processing root samples was designed and implemented to ease the financial burden and obtain more accurate measurements of belowground biomass. More fine root mass was recovered using the new methodology compared with traditional hand-washing methods resulting in more accurate assessments of treatment effects on belowground biomass.

A modified factorial design was implemented to test the interactions of military and land management disturbances. Control, mowing, and burning land management practices were applied to each block and military disturbance was applied in four levels including a control, light trafficking, one year of recovery, and a an additional year of light trafficking.

In-situ measurements were also identified as being good indicators of belowground biomass. This research found that percent live vegetation cover and cone index, penetrometer measurements, from 15.24 cm to 30.48 cm, were best at describing the belowground biomass observed. Findings from this research agreed with those of Passoiura (1991), Gill et al. (2002), Paruelo et al. (2000), and MacDonald et al. (2012).

CHAPTER 2: OBJECTIVES

The objective of this research was to observe changes in belowground biomass due to land management techniques and military training in order to recommend best management practices for increasing soil strength.

Specific objectives included:

1. Compile database of measurements related to soil physical properties, vegetation physiological properties, and other measurements known to describe soil and ecosystem health.
2. Design, construct, and evaluate an efficient, low cost method to separate belowground biomass from soil core samples.
3. Determine the effect of land management and military vehicle disturbance on below ground biomass observations. Also determine covariates which are easily measured by land managers and help describe variability associated with belowground biomass measurements.

CHAPTER 3: REVIEW OF LITERATURE

3.1 Belowground Biomass Changes Due to Land Management

Gebhart (2013) performed a meta-analysis examining changes in belowground biomass due to land management practices and vehicle disturbance. All research considered pertinent was carried out in tallgrass, Flinthill, or Konza prairie ecosystems unless noted otherwise. Some research employed destructive measurement of root biomass through soil cores, soil monoliths, soil blocks, or soil trenches. Due to the difficulty of doing research on belowground biomass and taking direct measurements, surrogates could be chosen as best estimates of changes in belowground biomass.

Changes in microbial biomass could be used as an indicator of changing root biomass. Microbial carbon (MBC) is a sensitive indicator of soil organic carbon so changes in MBC could be used to make rough estimates of changes in root mass due to burning, mowing, and grazing. Similarly, soil respiration measurements could be used to make predictions of the effects of burning, mowing, and grazing on root mass. Roots are a major source of carbon dioxide, due to respiration, so measurements of soil respiration can also be an excellent indicator of root mass.

Articles using direct measurements are discussed below, but those using a meta-analysis attempt to gain insight into changes in belowground biomass will not be discussed. All estimates of root mass changes due to land management practices are given in Table 3.1 in terms of percent increase or decrease when compared to a control plot.

Table 3.1: Estimated changes in belowground biomass by land management practice (Modified from Gebhart, 2013)

Article	Burn (%)	Mow (%)	Graze (%)
Johnson and Matchett (2011)	+25		
Tufekcioglu et al. (1999)	+15		
Heath (1985)	-15		
Ojima et al. (1994)	+40		
Ojima (1987)	+21%		
Olds (1969)	±0%		
Hadley and Kieckhefer (1963)	+20%		
Garcia et al. (1994) Followed by dry	-3 to 5%	-11 to 18%	
Followed by wet	+5-8%		
Benning and Seastedt (1997)	+1%	-2%	
Kitchen et al. (2009)	+48%	+7%	
Gibson et al. (1993)	+7%	-17%	
Kucera and Dahlman (1968)	+39%		
Bremer et al. (2002)	+3%	-8%	
Mielnick and Dugas (2000)	+7%		
Collins (1987)	+ 102%		+11%
Collins (1987)	+33%		-20%
Callaham et al. (2003)	+6%	-33%	
Bremer et al. (1998)		-17%	
Fiala et al. (2009) Followed by dry		-15%	
Richards et al. (1984) Short/Mixed Prairie		-20%	

Table 3.1 (cont.): Estimated changes in belowground biomass by land management practice (Modified from Gebhart, 2013)

Article	Burn (%)	Mow (%)	Graze (%)
Detling et al. (1979) Short/Mixed Prairie			-30%
Todd et al. (1992)		-28%	
Biondini et al. (1998) Mixed Prairie			-16%
Wilsey et al. (1997)		-15%	
Engel et al. (1998) As defoliation increases		-14 to -33%	
Polley and Detling (1989)			-30%
Dickinson and Polwart (1982) Amenity		+46%	

3.1.1 Burning

Kitchen et al. (2009) researched changes in belowground biomass following spring burning for 13 years. The experiment was conducted in the Konza tallgrass prairie located in the northeastern Kansas Flint Hills adjacent to Fort Riley Army Installation. The design was a complete factorial with the effects of fire, mowing, and the interaction of both tested. Annual burning was found to increase belowground biomass by 48%. There was a positive effect of burning in the absence of mowing. This study looked at distributions of roots from 0-90 cm in depth with intervals of 0-10, 10-20, 20-40, 40-60, and 60-90 cm. It was found that burning increased root biomass in each interval but was only significant at the shallowest (0 – 10 cm) and the deepest (60 – 90 cm) intervals. Annual burning was also found to increase aboveground biomass, increased stocks of carbon (C) and nitrogen (N) in root biomass, decreased root tissue quality (less N present), and led to proportionally deeper root distributions when compared to unburned treatments.

Benning, T. L. and Seastedt, T. R. (1997) performed a similar experiment but also tested addition of nitrogen to burned, mowed, and the interaction of burned and mowed plots. This study was conducted at the same location in the Konza Prairie Research Natural Area as Kitchen et al. (2009). Total root biomass from treatments burned and not mowed was 921 g/m^2 and treatments not burned or mowed had a total root biomass of 699 g/m^2; the 75.9% increase was significant ($p \leq 0.05$). Benning and Seastedt (1997) also found that N levels were 8.5 g/m^2 lower in plots burned, un-mowed, and unfertilized.

At the University of Missouri Prairie Research Station, Dahlman and Kucera (1968) found plots excluded from burning treatments for six years had 39% less biomass in the 0-5 cm depth. It was also reported that 65% of all biomass occurs within this interval. The largest differences in biomass were seen in the rhizomes of the Big Bluestem, *Andropogon gerardi v. Vitman*, stand of grass. Rhizomes are underground, horizontal stems present in some grass species such as Big Bluestem. An 82% reduction was observed in rhizome dry weights when burning was absent but only in the 2.5-5 cm interval. It was concluded that accumulation of litter over multiple years without burning was the single most important reason for the decline of tallgrass densities.

Another study by Johnson and Matchett (2001) looked at changes in belowground biomass following annual burning and grazing. The study, took place at the Konza Prairie Research Natural Area, but in different locations than the previous two studies. Annually burned plots increased root productivity by nearly 25% compared to production of non-burned sites. Sites were considered unburned after the absence of fire for at least four years. Nitrogen concentrations were roughly 30% lower in burned plots compared to unburned plots. Nitrogen concentrations were higher in grazed plots when annual burning was present compared to no burning and no grazing. Higher N concentrations suggest that root tissue quality improves with the presence of grazers; in this case the grazer was bison.

Using the CENTURY soil organic carbon model developed by Parton (1996) to simulate changes in plant production and nutrient cycling, Ojima et al. (1990) reported 79% higher belowground production rates after two years of annual burning and 67% higher production after prolonged burning took place (18 years). C:N ratio for burned simulations was 10.5 for C and 9.5 for N in unburned simulations. The literature reported 16% decreases in microbial N and 14 % decreases in microbial C; agreeing with the simulations.

3.1.2 Haying/Mowing

Kitchen et al. (2009) reported insignificant changes in root mass when only mowing was present. Root mass was decreased by approximately 32% when mowing was done in conjunction with burning compared to control plots. It was also found that mowing tended to shift biomass distributions toward the surface. Sixty percent of the total fine root biomass was found in the upper 10 cm under mowing treatments; both unburned and burned interactions with mowing where considered. All unmowed treatments had 51% of total fine root biomass in the upper 10 cm. Root tissue N was reduced by mowing and the combination of mowing and burning in the entire 0-90cm profile.

Benning and Seastedt (1997) found that mowing increased dead root presence. Mowing had no significant effect on root mass nor did it have an effect within growing seasons. Rather, most differences were seen between growing seasons. After four years of treatment, root mass varied little, but rhizome mass was most varied between the fixed effect treatments of mowing, burning, and control.

A study by Dickinson and Polwart (1982) looked at above- and belowground relationships in amenity grasslands, lawns, and recreational fields. Belowground biomass was considered the first 10 cm below the surface; it was reported that 80% of root mass was present in this region. Five blocks were used with three fixed effect treatments in each: these were heavily mowed, intermittently mowed, and a control with neither treatment. Heavy mowing was considered six cuttings per year with aboveground portion removed, light mowing was considered one cutting per year with aboveground portion removed, and the control had no cuttings during testing. It was proven that heavy mowing increases belowground biomass significantly when carried out in consecutive years. Light mowing caused indiscernible decreases. Cessation of mowing showed decreases in presence of root and rhizomes, 46 % and 61% respectively.

Todd et al. (1992) saw decreases in belowground biomass following two years of mowing. This study took place in the Konza on an upland silty clay loam. Twelve plots were established in a randomized complete block design with four replications and three levels of mowing: control, three week, and six week intervals. Live root mass decreased by 28% while presence of dead root increased 24% over both mowing intensities. Increased mowing frequency decreased live root mass even further when compared to the control and also increased dead root mass.

Turner et al. (1993) conducted two mowing experiments simultaneously. The first looked at mowing height and mowing intensity on production of above- and belowground biomass. This study used 24 plots with one-third being mowed six times during the growing season, one-third mowed three times, and the final third left unmowed. Six replicates of mowing treatments were created: unmowed, mowed to 5 cm, mowed to 10 cm, and mowed to 20 cm. The second looked at complete foliage removal one, three, and six times during the growing season. These treatments were applied to 20 plots to create five replicates of the following treatments: unmowed, mowed 1 time, mowed three times, and mowed six times. Plots mowed six times had approximately 30% reduction in live root mass. Dead root mass increased 14-29% on mowed plots when compared to unmowed treatments. Nitrogen was reduced in live rhizomes but no differences in N were found in dead root biomass. Grass root biomass comprised 91% of biomass, including live and dead, with a ratio of dead to live of 4.5 on average, ranging from 2.9 to 6.6.

3.2 Belowground Biomass Changes Due to Vehicle Disturbance

Limited literature exists looking at the effects of military disturbance on belowground biomass. There are additional effects that could be linked to other areas of research such as agriculture that look at effects of soil properties on crop root growth. Some of these effects are discussed later but the difference between established tallgrass prairie and establishing a root system during one growing season in a plowed environment are very difficult to compare and cannot be used as a complete surrogate.

One study looked at recovery of a shortgrass steppe after varying depths of scraping (Williams and Munns, 1979). The study looked at the heavy impacts and their interactions with grazing. The literature is unpublished, but heavy impacts were found to reduce belowground biomass by 45% and 65% when grazing was present with scraping.

3.3 Contribution of Research to Literature

A comprehensive dataset will be compiled to study not only the effects of land management and military disturbance on belowground biomass, but also many other topics important to land managers. Included in the dataset are soil physical and nutrient properties, soil strength measurements, aboveground vegetation biometrics, species data, belowground biometrics, and nematode analysis. Other hypotheses could be tested based on data collected, but not included in this thesis.

This research will begin a framework for understanding military disturbance interactions and influences belowground biomass. The approach will include sampling and processing methodology for collection of biomass and soil strength data. Also, a new methodology for separating roots from soil may be adopted by researchers who are constrained by time and funding.

Recovery of vegetation following military training depends on the quality of belowground resources. This paper will give land managers insight to the outcomes of choosing land management practices, timing of practices, assigning a level of training, and determining the consequences of combining land management practices with varying training intensities. Land managers will also be able to use necessary, quantitative measurements to determine training land health and land carrying capacity in the presence of combined land management with military training intensities.

CHAPTER 4: METHODS AND MATERIALS

Methods and materials presented in this thesis were developed at a study site located at the US Army Corps of Engineers Engineering Research and Development Center-Constructional Engineering Research Laboratory. These methods and the relationships between collected parameters were detailed in *Cumulative Interactions for the Military Vehicle Impact Assessment* (Koch et al., 2010).

4.1 Site Descriptions

Fort Riley is located in northeast Kansas within the Flint Hills. The Flint Hills grassland encompasses 1.6 million ha (almost 4 million acres), stretching from southern Nebraska into northeast Oklahoma. This area contains the largest acreage of untilled tallgrass prairie in North America (Knapp and Seastedt, 1998). Fort Riley is an Army base established in 1853, and is now 40,782.2 ha (100,775 acres). Approximately 28,328 ha (70,000 acres) is available for maneuver training, separated into 103 training areas. The heaviest used areas are occupied for 160-210 days per year. (U.S. Army, 1994)

Mean monthly temperatures range from -2.33°C (27.8°F) in January to 26.61°C (79.9°F) in July. Mean annual rainfall is 884 mm (34.8 in.) (NOAA 2002). Seventy percent of precipitation occurs during the growing season (Hayden, 1998).

Two experimental sites were established at Fort Riley in 2009 by Fort Riley, Kansas State University, and CERL. CERL utilized a subset of plots for this study. Soils differ between the two experimental sites. The first site, Gulf, was located in one of the most northern training areas in Riley county; this site was denoted EE because of the training area. EE was dominated by moderately well drained, silty clay loam soils which are part of the Wymore series (Soil Survey Staff). Wymore soils are classified as fine, smectitic, mesic Aquertic Argiudolls. The second site, Quebec, was located on the westernmost side of the base in Geary county; this site was denoted BB. The BB site was predominately comprised of moderately well drained, silty clay loam soils as part of the Crete series. Crete soils are classified as fine, smectitic, mesic Pachic Arguistolls (Soil Survey Staff). The layout of blocks at the EE site is shown in Figure 4.1 and the layout of BB blocks is shown in Figure 4.2. Only plots circled were utilized for this study.

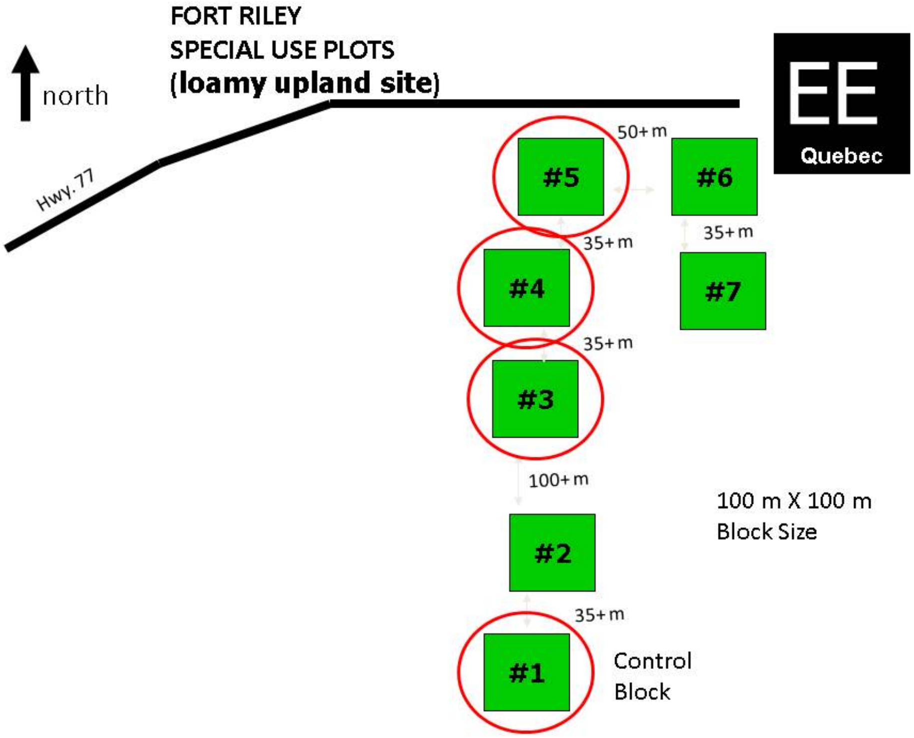

Figure 4.1: Block layout at site EE

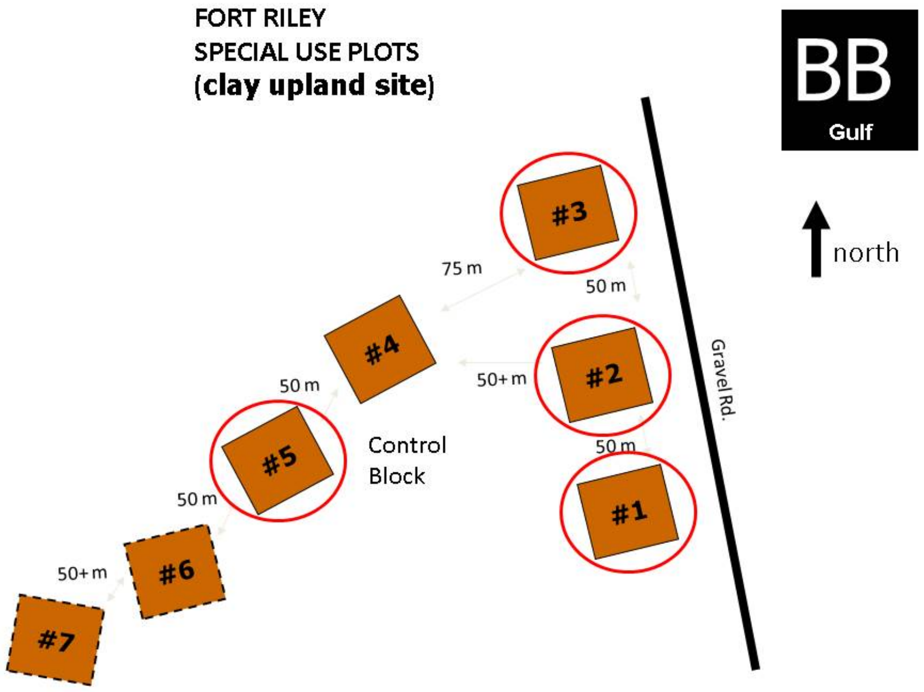

Figure 4.2: Block layout at site BB

4.2 Experimental Design

The two sites contained three experimental blocks. These three replicated blocks were treated as a modified, three by three, factorial design. The two treatment types were vehicle tracking and land management. Vehicle tracking had two levels of disturbance but had subsequent applications. The trafficking levels were control, light tracking, light tracking with one year of recovery, and light tracking followed by another year of light tracking. Light tracking consisted of three controlled complete passes within the same tracks. Land management had three levels control, haying, and prescribed burning.

4.3 Treatments

Blocks were established in the spring of 2010 using Fort Riley's special use plots located in areas designated for research specifically for projects to determine vehicle disturbances. Baseline data was collected in June of 2010 before any treatments were applied. Plot layout within block, as well as data collection locations, is shown in Figures 4.3 and 4.4 for 2011 and 2012 respectively.

4.3.1 Vehicle Disturbance

Fall tracking was a light treatment done on both treatment rows, six plots in each block, on October 27, 2010. The second trafficking treatment was done in the spring of 2012 on March 27th. The second treatment was only applied on the heavy impact plots totaling six passes over two years, for three plots per block.

Tracking was done with an M1A1 Abrams Main Battle Tank (M1A1 MBT) in 2010 and a M88A2 HERCULES Armored Recovery Vehicle (ARV) in 2012. The M1A1 MBT weighed 61,326 Kg (67.6 tons) and the M88 weighed 63,503 Kg (70 tons). The switch to the M88 was made after changes in policy regarding the use of the M1A1 MBT from the Kansas National Guard. The Engineering Research and Development Center – Geotechnical and Structures Laboratory (ERDC – GSL) considered these two armored vehicles identical. A M88 and M1A1 MBT have very similar footprints, chassis, and weights. The M1A1 MBT had a ground pressure of 94.3 kPa (13.8 psi) and the M88 had a ground pressure of 92.4 kPa (13.4 psi). The maximum speeds were 66.8 km/h (41.5 mph) for the M1A1 MBT and 40.2 km/h (25 mph) for the M88. (U.S. Army, 2013a; U.S. Army, 2013b)

4.3.2 Land Management

4.3.2.1 Haying

Native grass hay cutting is allowed on Ft. Riley through contracted leases. Hay cutting assists in maintaining open space used for training, reducing potential for wildfires, suppressing woody plant invasion into native prairie, controlling invasive weeds, maintaining wildlife cover, and supplying local producers with livestock feed. On base grasslands, leased for hay, are harvested at most twice per year, prior to June 20. Every other year, fields are left to reestablish and leave standing biomass and litter as species habitat for the Henslow's sparrow and western harvest mouse (U.S. Army, 1994).

Haying treatments were applied by mowing and then raking. Mowing and raking were carried out by Ft. Riley ITAM. The first haying treatment was done on September 28, 2010 and the second treatment was done on September 30, 2011. These dates were outside the regulated time periods for the lessees, July 15 to August 15, but that time was necessary for the crews applying the treatments.

4.3.2.2 Prescribed Burning

Prescribed burning at Fort Riley typically occurs between December and early May. When burning takes place in the spring, warm season grass and their associated forbs are benefited and annual cool season grasses are controlled. Spring burning is not ideal for shrub control or other invasive plants that establish later in the year. Mid-April through mid-August are discouraged for prescribed burning times due to nesting of game and nongame birds. (U.S. Army, 1994)

Controlled burns took place on April 22, 2011 on BB plots and May 15, 2011 on EE plots. In 2012 BB was burned on March 3rd and EE plots were burned on April 21st. Prescribed burns can be difficult to contain and occasionally wildfires occur on base. In 2011 the controlled burn at the BB site in block one crept into the mowed treatment approximately 10 m in the worst areas and completely burned block two. In March 2012, the entire BB site was burned by a wildfire; the wildfire was utilized as the burn treatment and occurred on the 3rd of March.

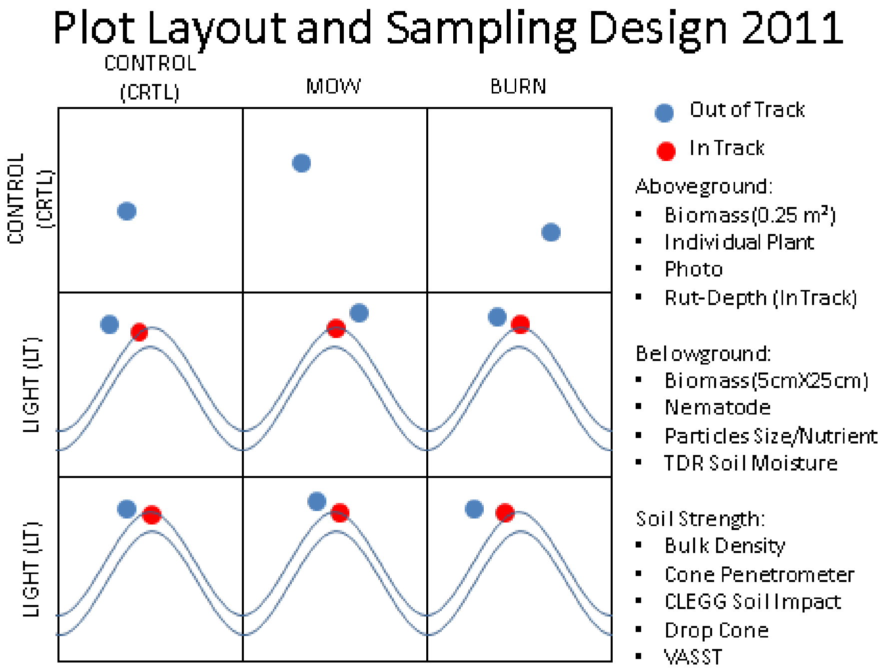

Figure 4.3: Block layout of both fixed effect treatments land management and traffic intensity in 2011

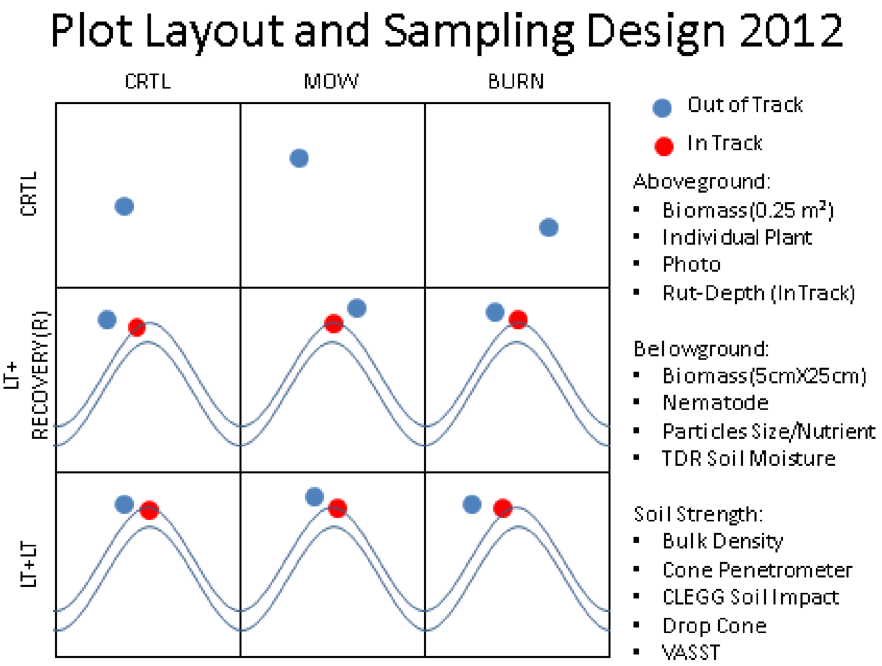

Figure 4.4: Block layout of both fixed effect treatments land management and traffic intensity in 2012

4.4 Field Sampling Methods

Field sampling efforts were conducted in the summers of 2010, 2011, and 2012. Sampling in 2010 took longer than estimated and was divided between two weeks, sampling took place on June 1st, 2nd, and 3rd and again in July on the 13th and 14th. In 2011, sampling took place during June 28th, 29th, and 30th and again in 2012 on June 26th, 27th and 28th.

4.4.1 Soil Sampling

Parameters commonly used to describe a particular soil for engineers and those in the agricultural field were: soil type, structure, particle size distribution, Atterberg limits, moisture content, and bulk density (Shoop, 1993). Field measurements were made quickly and inexpensively compared to performing the same measurement in a highly controlled laboratory setting. Methods used to describe these characteristics are discussed below.

4.4.1.1 Soil Moisture

4.4.1.1.1 Time Domain Reflectometry (TDR) Probe

In situ soil moisture was measured using a TDR probe by introducing a voltage pulse and measuring wave propagation time between probes inserted into the ground at a specified distance apart.

$$v_p = v/c_o = (\varepsilon\mu)^{0.5} \qquad \text{Eq. 4.1}$$

v_p = fraction of the speed of light observed in a vacuum

μ = magnetic permeability of dielectric material

ε = permittivity

Volumetric water content has been shown to be a function of permittivity (Topp et al., 1980). Soil presents a complicated combination of soil, air, and water. Soil comprised of minerals and organic matter has very low permittivity values, air is essentially unity, and water is the only rapidly changing portion contributing to permittivity. The relationship between permittivity and water content has been reported as being polynomial in nature.

A Spectrum Technologies Inc. Fieldscout TDR 300 was used to measure volumetric moisture content. The TDR measurements by nature take averages over the entire length of probes; therefore, the longest probes were used measuring 20 cm (8 in) in length. Probes were inserted into the soil to 20 cm and then a reading was stored in the built in data logger. Probe length and soil mode were chosen to provide more accurate readings. Soil modes were standard and high clay [content]. According to Evett (2003), TDR measurements can be inaccurate due to high cationic exchange capacity (CEC). Soils with high clay content and are highly charged or contain high organic matter can exhibit CEC challenges. Dealing with silty clay loams at the two experimental sites at Ft. Riley, the standard calibration was used with the TDR.

4.4.1.1.2 Direct Soil Moisture

Volumetric soil moisture was measured along with bulk density, section 4.4.2.2.4. Differences between wet weights, at moisture level collected in field, and dry weights divided by the dry weight result in gravimetric moisture content (g/g). Volumetric moisture content was measured directly from the bulk density sample because the volume was known.

$$\theta = \frac{m_{wet} - m_{dry}}{\rho_w \cdot V_b} \qquad \text{Eq. 4.2}$$

θ = Volumetric water content

m_{wet} = Weight before drying (g)

m_{dry} = Weight after drying (g)

ρ_w = Density of water (g/cm^3)

V_b = Volume of sample before drying (cm^3)

4.4.1.2 Soil Strength Properties

4.4.1.2.1 Cone Penetration Test

The cone penetration test has historically been used to quantify trafficability in military and agricultural settings. Cone penetration has been used to predict the trafficability of an off-road vehicle (Freitag and Richardson, 1968; Wismer and Luth, 1972), characterization of soil in terms of crop growing ability (Raghavan and McKyes, 1977), and resistance to root penetration and seedling emergence (Bowen, 1976; Taylor and Gardner, 1963; Morton and Buchele, 1960; Chen and Weil, 2009). Cone penetration was measured using a cone penetrometer. Penetrometers are comprised of a rod with standardized cone tip, differing depending on application, and a load cell or proving ring. The penetrometer is forced through the soil at a constant velocity and the force required to do so was recorded simultaneously with depth from the surface. The force required to push the cone through the soil profile is called the Cone Index (CI).

The United States Army Corps of Engineers Waterways Experimental Station developed a cone to be used for trafficability determination (WES, 1948). This method gave a choice of two cones. Both cones have a 30° circular cone, one with a base area of 3.23 cm^2 (0.5 in^2) and the other with 1.30 cm^2 (0.2 in^2). The 1.3 cm^2 cone was chosen based on the fines content in the soils of Ft. Riley.

Penetrometers now include load cells, sonar, and data loggers integrated into one instrument. Data loggers allow one person to perform a measurement and quickly store or reject readings. Field Scout SC 900 Soil Compaction Meter by Spectrum Technologies Inc. was the penetrometer used for this study. This penetrometer utilized sonar to record depth (cm) data and force per area (kPa) applied. The measurements were geocoded with a GPS unit and stored on the internal data logger, then uploaded to a computer in the lab. CI was reported with depth as the average force per area over a specified depth or as a gradient. At the beginning of the analysis CI was averaged over 2.54 cm by the apparatus and then later averaged over the top 15.24 cm and from 15.24 cm to 30.48 cm. One reading was taken at each collection site both in and out of track.

Many soil factors affect the outcome of the cone penetrometer readout including: soil moisture, bulk density, soil structure and type, root density, and insertion rate (Perumpral, 1987). Methods to better describe these factors are described in the following sections.

4.4.1.2.2 Drop-Cone Penetrometer

Drop-cone penetrometer has been used to measure compaction effects due to military activity (Jones, 2000). The drop cone, similar to the cone penetrometer, is a test used to subject the soil surface to a much larger force than the penetrometer. Using a 30° and 2 kg cone dropped from a height of 1 m, this test has the ability to exert a much larger force without taking very large equipment into the field. Tests have indicated significant linear relationships between drop cone penetration and soil moisture, vane shear strength indices, and rut depth (Godwin et al., 1991).

The drop cone was developed to take rapid and precise measurements. One potential problem with the drop-cone penetrometer was the larger amount of surface area measured compared to the static cone penetrometer. More area means less sensitivity. The measurement only takes into account the soil surface and inference cannot be made about soil below the surface (Jones, 2004).

The apparatus was comprised of a 1 m in length PVC tube, cone made to specifications, and graduated rod. The top of the cone was lifted flush with the tube and then released. Graduations of the rod indicate how deep the cone penetrated the soil surface. Three readings were taken at each collection site both in and out of track.

4.4.1.2.3 Clegg Impact Hammer

The California-bearing ratio, CBR, test is used to asses layers comprised of granular materials in pavements. CBR values have been correlated with soil properties such as plasticity indices, particle size distribution, bearing capacity, shear strength, density, and moisture content (Doshi and Guirguis, 1983). The CBR test is typically done in a laboratory environment and is detailed in ASTM standard D 1883-99. The laboratory method to determine CBR is time consuming; hence, it can be tedious and expensive. Other methods which could be correlated with the CBR have the potential to measure CBR in the field with more efficiency.

Density and soil moisture measurements in the field can be performed much easier, but do not always correlate well with soil strength (Al-Amoudi, 2002a). Other tests have been found to correlate well with CBR values such as the vane shear test, cone penetrometer, unconfined compression, and Texas triaxial tests (Ladner, 1973; Clegg, 1983a; Al-Joulani, 1987) but are unable to completely replace the CBR value because of the nature of the impact or laboratory limitations (Al-Amoudi et al., 2002b). A device called a Clegg impact soil tester, has been proven to be capable of producing CBR values consistent with laboratory tests using equation three (Al-Amoudi et al., 2002b). This equation has a coefficient of determination (R^2) of 0.850 and is used in the civil engineering community for conversion of Clegg impact values (CIV) to CBR values. Al-Amoud, et al. (2002b) is one of few studies attempting to make inferences about correlations between CBR and CIV (Kraft et al., 1991; Akire, 1987).

$$\text{CBR} = 0.1691\,(\text{CIV})^{1.695} \qquad \text{Eq. 4.3}$$

A Clegg impact soil tester consisted of a 2.25 kg hammer based on a modified Proctor hammer, a piezoelectric accelerometer and a digital display to show CIV after each measurement. The hammer was raised to a height of 45 cm before releasing and then considered one blow. CIV was recorded after 4 blows, to have stabilized rebounds of the hammer. The CIV was calculated based on the rate at which the hammer rebounds; rebound is related to soil strength, density, or stiffness.

The Clegg soil impact tester was repeatable and capable of taking rapid measurements. As with the drop-cone penetrometer, the Clegg impact hammer takes a measurement over a much larger area of soil surface and has been found to be less sensitive than methods like the cone penetrometer (Shoop, 1993). The Clegg impact hammer also has similar limitations to the drop-cone penetrometer in making inferences about soil strength below the soil surface. One Clegg reading was taken at each collection site both in and out of track.

4.4.1.2.4 Bulk Density

Bulk density samples were taken with standard rings in a manner described in NRCS, 2001. Rings were 7.62 cm (3 in) inner diameter and 7.62 cm (3 in) in height, with volume 115.77 cm^3. Soil samples were taken using a sampler design from CRREL. The sampler was designed to minimize compaction and take advantage of gravity; all while using the standard ring size reducing variability.

Wet soil samples were weighed before drying. Drying took place for a minimum of 24 hours or until the weight ceased to change. Temperature was set at 105°C with a maximum temperature allowed of 110°C in a forced air oven. The temperature and duration chosen were based on the Parent and Caron (1993) method. Bulk density samples were taken at each collection site both in and out of track.

4.4.2 Biomass Sampling

4.4.2.1 Aboveground Biomass

U.S. Army Land Condition-Trend Analysis (LCTA) has developed standard methods for assessing vegetation dynamics on military training lands. LCTA line-transect methods were an effort to standardize studies across military installations to help meet environmental regulation compliance and evaluate military training needs. The LCTA’s monitoring techniques had strengths in assessing ground cover, surface disturbance, and vertical distribution of vegetation, which were useful in estimating soil erosion, military concealment cover, wildlife habitat, species diversity, and ground-truthing remote sensing data (Tazik et al., 1992).

Line intercept methods of studying vegetation are time consuming and not well suited for collecting species richness data compared to a Daubenmire frame or quadrat (Prosser et al., 2003; Godínez-Alvarez, 2008). Quadrats are also better suited for use in collecting vegetation on a per unit area basis. LCTA methods only look at 60 cm^2 per transect; whereas, a 0.25 m^2 quadrat samples 2500 cm^2. LCTA transects can overcome coverage limitations with more samples but time is a limiting factor.

Choosing a quadrat size and shape was also of concern. Quadrat shapes are considered to impact variance on species detection but have little effect on total herbage estimates (Brummer et al., 1994). As quadrat size increases, the ability to account for more species with less variance is observed but statistical efficiency is lower because of fewer observations. Smaller quadrats may be statistically better, but more samples are necessary.

Biomass was sampled in random locations within a track and in adjacent representative areas within plots with no trafficking. A 0.25 m^2 square quadrat was used due to limitations in size and ease of taking overhead images. Photographs were taken when all vegetation was present, again at 15.24 cm (6 in), and once all vegetation and litter had been removed, leaving only bare soil. Visual plant cover estimates are more rapid (Sykes et al., 1983). However, according to Stocking (1994), vertical photographs taken with quadrats were the most practical and least costly method of directly measuring vegetative cover. Denight (2005) used a detailed approach to identify the best method to directly measure vegetation cover using digital photography. Using methods laid out by Denight, white PVC tubing was used for the frames. Cameras were mounted 1.0 m above the quadrat and centered making the process repeatable and unbiased. The high contrast between the white and ground cover made image analysis easier (see Section 4.5.1.1). All clipped vegetation was placed into dried, pre-weighed and labeled paper bags. Weights were taken after drying until dry weights have not changed (see Section 4.5.1.1).

After collecting above- and belowground biomass samples in 2010, not knowing the dominant species was of concern. In subsequent years, soil cores were taken outside the quadrat and biometrics of a representative plant specimen were recorded. Height and species were recorded for each individual plant directly above a soil core. The plant was then clipped at soil surface and placed in a pre-weighed and labeled paper bag. These specimens were dried and weighed separate, as described in Section 4.5.1.1.

In 2011 and 2012, aboveground biomass samples were taken at each collection site both in and out of track, resulting in 108 samples from each of the quadrat samples and belowground samples for each year.

4.4.2.2 Belowground Biomass

Knowledge of belowground biomass rooting structures is crucial in order to understand numerous biological and physical processes in soil and vegetation interactions. Rooting structures, more specifically root hairs, provide a method for plants to uptake nutrients and soil moisture (Gibson, 2009). Roots influence soil structure by creating macropores, forming aggregates, causing wetting and drying cycles, secreting solidifying compounds, anchoring aggregates together, and providing a food source for microflora and fauna (Angers and Caron, 1998). Additionally, belowground biomass stabilizes the soil structure increasing soil trafficability and reduces soil erosion (Frei, 2009; Steichen et al., 2008). However, studying belowground biomass is inherently a difficult task as the subject in question is concealed in the soil profile.

The process of performing belowground biomass research therefore becomes tedious and expensive, with a large amount of time required to extract a root sample from a soil core in order to obtain a dry root weight. Certain sampling methods are more suitable for certain quantifiable parameters than others. For instance, soil cores are better at estimating biomass, root length, and root surface area whereas a wall profile is better at determining live root diameter (Bledsoe et al., 1999). Excavation, wall profiling, or pinboard monolith sampling are all destructive like soil cores, but the destruction caused by such sampling techniques would interfere with future land uses (Anderson and Ingram, 1993). In the case of this project, the sampling sites are on live military training areas, eliminating the possibility of using these sampling techniques. Soil cores were chosen based on their ability to acquire quantifiable data at one instance throughout the year in a less destructive manner.

At the Konza prairie, there exists two to four times more belowground biomass than aboveground biomass with peak belowground biomass ranging from 700-1200 g/m^2 at a depth of 90 cm (Risser, 1981; Seastedt and Ramundo, 1990). It was also estimated that approximately 80% of all belowground biomass occurs in the upper 25 cm of the soil profile (Kucera and Dahlman, 1968). Soil samples, 5 cm in diameter and 25 cm in length, were considered best for characterizing vegetation both in and out of track.

While taking a core 5 cm in diameter was rather difficult in the soils at these two locations, the method was recommended over taking a large number of very small cores. Larger cores allowed a sample to be taken over an individual plant rather taking many smaller cores around a plant or many different types of plants. Belowground biomass samples were taken at each collection site both in and out of track, totaling 108 for each year.

4.5 Laboratory Methods

4.5.1 Biomass Sample Processing

4.5.1.1 Aboveground Biomass

Biomass samples were received in the laboratory two to four days after collection. The entire sample and bag was placed into the oven and dried at a temperature of 65° C for a period of three to four days, or until the mass of the bag and vegetation stabilized. The mass of the pre-weighed paper bag and the combined mass were recorded to calculate final dry mass of the vegetation. This process was carried out on the vegetation samples taken from the quadrats and the individual samples taken above the belowground biomass soil cores. Dried samples were then double bagged and archived.

Digital images of the quadrats were processed with Assess photo analysis software, to determine percent live vegetation cover as well as contributing percentages of grass and forbs to the live cover. Assess 2.0, a plant disease quantification program, analyzes ground cover and was used to separate different vegetation types by differing spectrums. First, the images were relabeled by sample ID. Photos were imported into Assess 2.0 and then an area of interest (AOI) was chosen based on the inner edge of the quadrats. Top and bottom spectrum values were chosen to include all live green ground cover, percent cover within the AOI. The spectrum upper and lower values were then adjusted to only include grass and forb portions of live ground cover. (Náter and Howard, 2011)

4.5.1.2 Belowground Biomass

Belowground biomass samples were initially weighed and recorded, then refrigerated for up to one week before washing occurred. Before data could be extracted from the soil cores, a washing process had to be implemented to separate biomass from the soil. Many separation methods have been developed in the past, but the accepted method used in interdisciplinary research has been the elutriation method (Anderson and Ingram, 1993). Elutriation requires water and air pressure to perturb samples and separate soil from roots. Biomass then floats up a column and is caught in a mesh strainer allowing soil to freely move through mesh. Full descriptions of elutriation methods are explained in Smucker et al. (1982) and Chotte et al. (1995).

A common alternative to the elutriation method is hand washing presoaked samples with water. Hand washing samples is typically done on a 0.3-0.5 mm mesh sieve or stack of sieves with a 1.1 mm sieve on top and a 0.3 mm sieve on bottom (Van Noordwijk, 1993). The best approach is to wash samples upon arrival and then store in refrigerator for a maximum of a few days. Hand washing is a long process either requiring many people or creative storage methods to effectively process many samples. Retention of fine-root mass, smaller than 1 mm diameter, is also highly dependent on the choice of sieve size (Amato and Pardo, 1994).

Organic matter, clays, and root diameter play a large role in the effectiveness of washing methods. Pressurized air and water are quite destructive to the integrity of the sample and not as effective on samples containing a high percentage of clay or organic matter (Van Noordwijk, 1993; Rice et al., 1998). Hand washing produces similar results without using enormous amounts of water; however, it is tedious when retention of fine-root mass is required and highly variable due to pressure applied during wash. While breaking roots into shorter pieces is not an issue for finding total root length or classifying by diameter, attempting to separate smaller root particles can be problematic. Overnight soaking can be used to break down aggregates before washing takes place. Other extreme measures call for an overnight soak in 5% sodium hexametaphosphate (Van Noordwijk, 1993). However, the use of a surfactant in the soaking process can stain and dehydrate root tissue. Van Noordwijk and Floris, (1979) observed 15% losses in dry matter when using tetrasodium pyrophosphate as a dispersing agent.

Initially, a hand washing method described previously was deployed for 2010 samples. However, this process was ineffective as there were observed inconsistencies between the people hand washing the samples. Additionally, much of the fine-root mass was lost, resulting in a very low variability among samples. In a search for alternative methods, additional soil cores were washed in a root hydropneumatic elutriation system as described in Smucker et al. (1982). The sample was split in half between two different chambers. Samples emerged after 45 minutes with clay aggregates still intact, containing a considerable amount of fine roots. Equipment and estimated labor costs from the trial made the elutriation system unfeasible for the remaining two years of the study. A method described in Benjamin and Nielsen (2004) was another style of washer considered. Such a method required commercial line strainers arranged in a radial fashion. A rotary root washer design was intriguing, but seemed to require a great deal of fabrication and expensive parts.

Challenges with the high clay content at the study sites, coupled with the large amount of biomass and number of samples planned, necessitated a new method to separate soil from biomass. A design for a new root washing process and equipment was then developed for separating native, tallgrass prairie roots from compacted clay soil samples with a high percentage of organic matter.

The basic principle of the root washer was a frame to hold the root samples oscillating back and forth through a circulating water bath (Figure 4.5). A whirlpool tub served as the base of the apparatus. The pre-constructed base was selected since it was low cost, could hold a large volume of water, required no assembly, contained a water circulation pump with an on/off switch, and conserved water. Though the base had water circulation system and basin to hold all the samples, additional agitation was necessary to move soil away from the intact sample.

Figure 4.5: The final root washer design meeting all necessary criteria

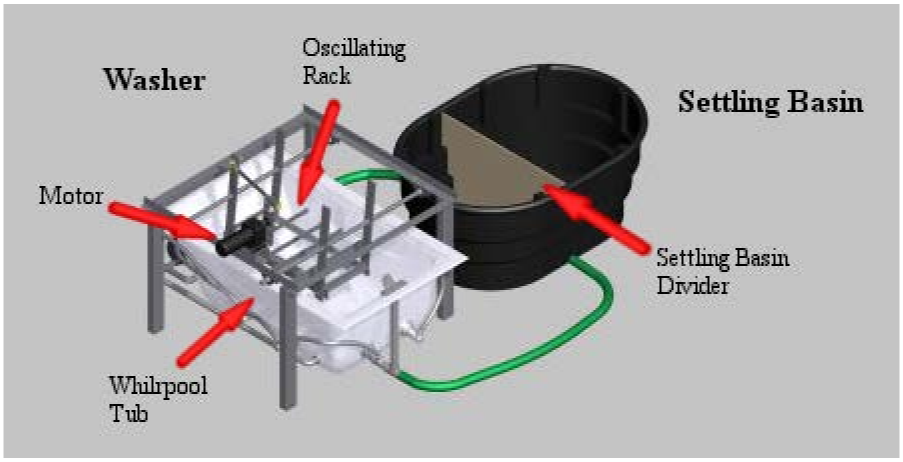

Figure 4.6: Labeled parts with isometric view

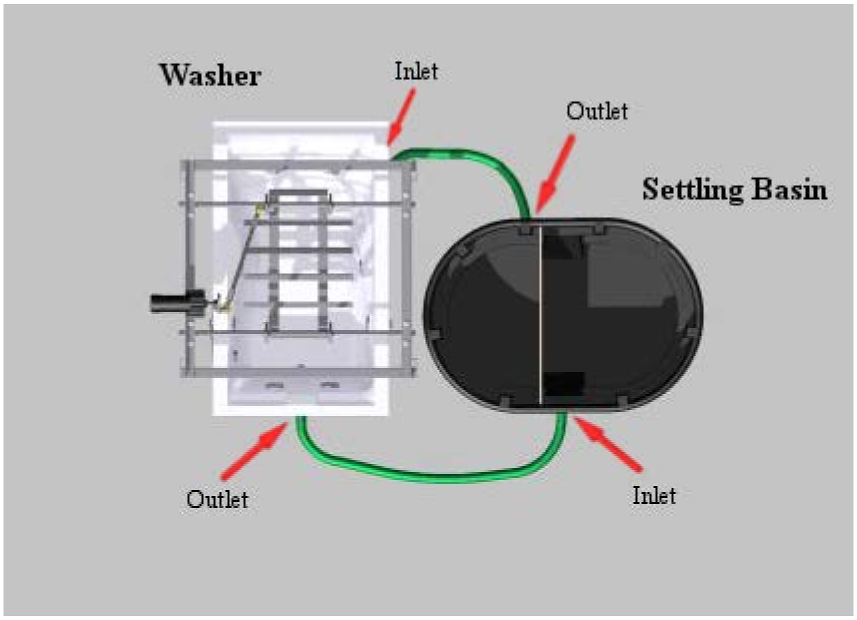

Figure 4.7: Labeled inlets and outlets with view from the top

The oscillating rack was designed to keep samples in constant movement in the water bath, in order to further separate the soil from the roots. Polypropylene, mono filament, mesh, filter bags, with 125 micron sieve size all of which contained samples, were secured to the oscillating rack. These bags allowed water and separated soil particles to pass through the tight mesh while retaining biomass. The moving rack that held the bags was constructed out of extruded, cold rolled steel materials including 90 degree angle, strap and round bar. An electric motor powered the motion of the rack through a crank. The crank could be mounted in different lengths to change the linear distance covered by the oscillating rack; this design allowed for different sized tubs to be used if necessary.

A filtration system was added in order to reuse the wash water. Since water was to be recirculated, water already at sediment holding capacity would not have been effective at further removing soil. A sand filter was tested; however it quickly was clogged with fine clay particles. Flocculants were not desirable due to the potential of clogging the inside of filter bags still containing soil and the unknown effect on the surface area of the root tissue. A settling basin was concluded to be effective at removing small sand and silt particles. This also helped reduce wear and tear on the whirlpool pump. Figure 4.5 shows the final design of the system.

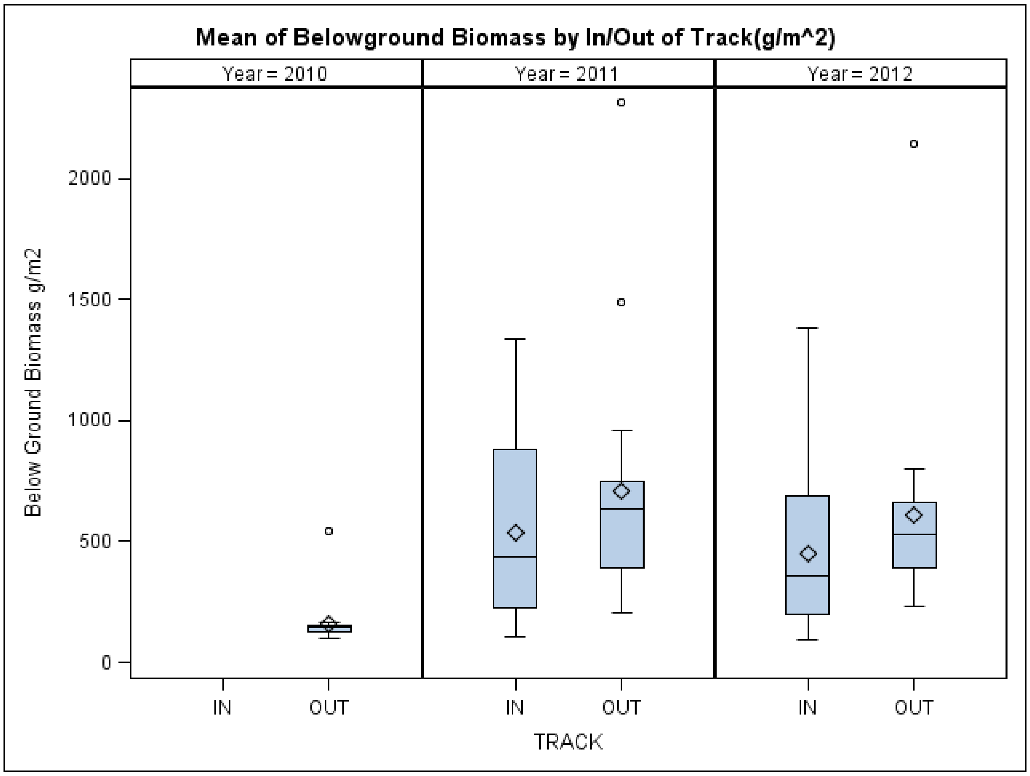

Figure 4.8: Belowground biomass comparison by year then in/out of track

As illustrated in Figure 4.8, the variability in belowground biomass was much smaller in 2010 than in 2011-2012. Belowground biomass was removed from soil samples when using hand washing methods. Despite the fact that multiple people were performing the washing, variability was not observed in the distribution of belowground biomass. The only conclusion to be made, is hand washing method utilized in 2010 removed natural variability between belowground biomass samples. Belowground biomass values from 2011-2012 seen in Figure 4.8, illustrate the effectiveness of the newly devised root washer through the retention of more fine-root particles.

The total cost of all new parts was $2861.43 US. Labor required was 60 hours, two people working for 30 hrs. The process presented by (Benjamin and Nielsen, 2004) was similar, but no labor was included in their cost calculation and some of the more expensive parts were salvaged.

The apparatus described has washed over 400 samples since 2011. All wash water for the 400 samples, approximately 568 liters per 30 samples, was collected using rain barrels and condensation of refrigeration compressors. Only during final wash, was deionized water utilized for the new procedure. Elutriation and hand washing techniques require pressurized water sources; meaning municipal water must be used. Municipal water is clean requiring less time to completely remove soil from samples, since no other method utilizes recirculation. The samples being dealt with are approximately 490 cm^3, meaning an elutriation method would require four chambers, no more than 150 cm^3 in each, running simultaneously for over 10 minutes to achieve completion (Gillison's Variety Fabrication, 2012). This time does not include loading, unloading, and organizing samples. Hand washing requires approximately 45 min per sample and 19-57 liters of water. The automatic root washing method used approximately 19 liters of water per sample and takes an average 9.2 min per samples, n=336.

Efficiency of washing is important, but of greater concern was retention of fine roots. When using a porous membrane to allow soil through, 100% retention is not likely while maintaining a manageable wash time. Few studies have looked at sieve effects on the retention of root length and biomass (Amato and Pardo, 1994; Livesley et al., 1998; Van Noordwijk and Floris, 1979).

Amato and Pardo (1994) found that aperture openings of 2 mm and 1 mm collected 55% and 75% of weight but only 10% and 34% of length, respectively, compared to 0.2 mm opening size. Livesley et al. (1998) reported that root mass passing through a screen with a 0.5 mm opening but captured by a 0.25 mm screen size accounted for 20% of the total root length but an insignificant portion of the root mass. Mesh openings of 0.8, 0.6, 0.4, 0.250, and 0.125 mm were tested for time and root retention. Sizes were chosen based on availability and cost of material. Ten samples were tested in the initial performance testing. Each sample had 25 monofilament strings of varying length, coded by color, added to simulate fine roots. The lengths were 5, 10, 20, 40, and 80 mm and five of each size were embedded in a soil sample before washing. The strings were then recovered and counted after automated washing process had completed. The results are shown below in Table 4.1.

Table 4.1: Mesh opening size test results (N and S designate positions on oscillating rack)

	Recovered Number of Strings									
String (mm)	**125 (µm) N**	**125 (µ)m S**	**250 (µm) N**	**250 (µm) S**	**400 (µm) N**	**400 (µm) S**	**600 (µm) N**	**600 (µm) S**	**800 (µm) N**	**800 (µm) S**
5	1	4	0	2	0	0	0	0	0	0
10	3	5	0	0	0	0	0	0	0	0
20	5	5	0	2	3	1	0	0	1	0
40	5	5	0	0	0	0	0	0	0	0
80	5	5	1	3	2	3	1	0	2	0
Wash Time (min)	125	236	140	180	90	165	119	152	121	119

Of the different mesh sizes, only 0.125 mm opening bags were able to save both 5 mm and 10 mm strings. These results dictated 0.125 mm opening bags be used for processing of samples. However, the 0.125 mm mesh also captured fine, medium and coarse sands (Bureau of Plant Industry, Soils, and Agricultural Engineering, 1951). Fortunately, sandy soils wash much easier and larger mesh opening filter bags can be used to quickly wash sandy soils. If very fine roots are of great concern, gathering length data for surface area calculations, a mesh opening closest to the approximate root diameter should be used (Amato and Pardo, 1994). The time required to wash samples according to bag mesh size was inconclusive due to the small sample size. However, it does seem that the South position in the washer, denoted S in Table 4.1, appears to take more time than the North position for decreasing opening size.

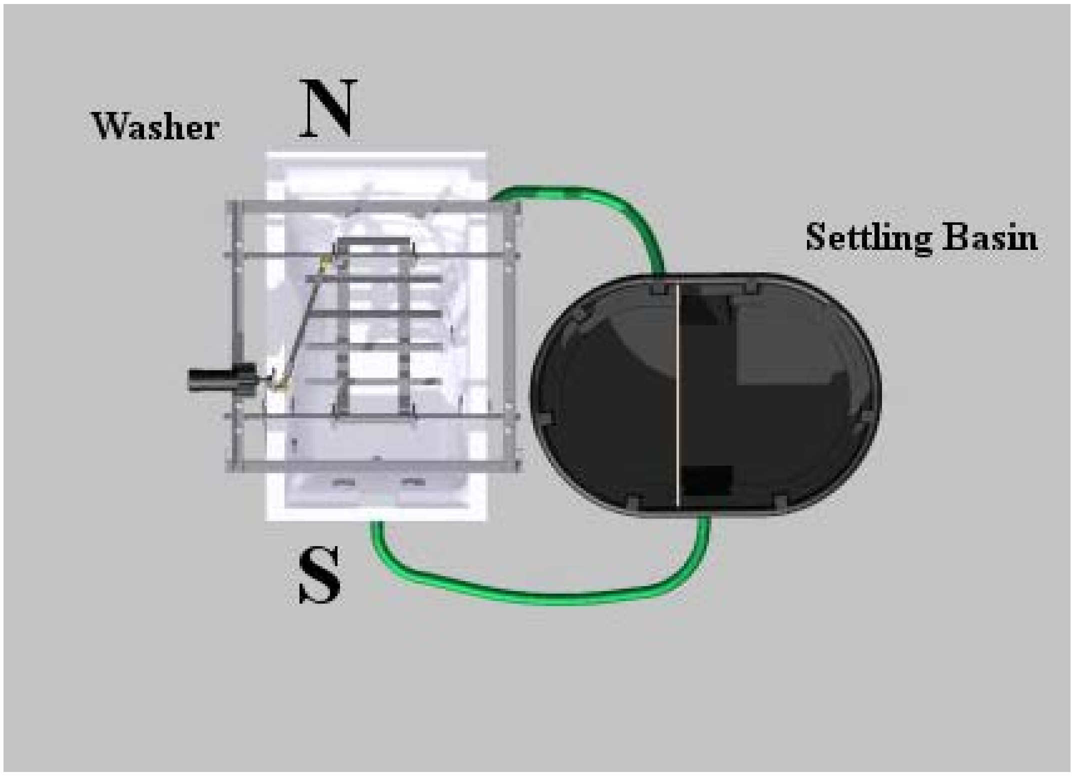

Figure 4.9: Depiction of North and South sides of the root washer

An additional test was performed to quantify differences between the hand washing method and the automated washing device. Samples were washed by hand as described previously, with all dirty water passing through the 1.1 mm sieve collected. The resulting water, soil, debris, and root that passed through the sieve were then poured through a new filter bag of 0.125 mm opening. This bag was then run through the new automated washing process to produce a difference of root and debris retained by the automated root washing technique.

Twelve samples were tested with the same treatment applied to all samples. Soil cores came from the same soil type and were washed until all aggregates had dissipated. Figures 4.10 and 4.11 illustrate the results of this test. While 0.2 g may appear insignificant, the soil cores cross sectional areas were only 20 cm^2. When extrapolated to g/m^2 this becomes a difference of 100 g/m^2. Debris was biomass found belowground not to be considered root.

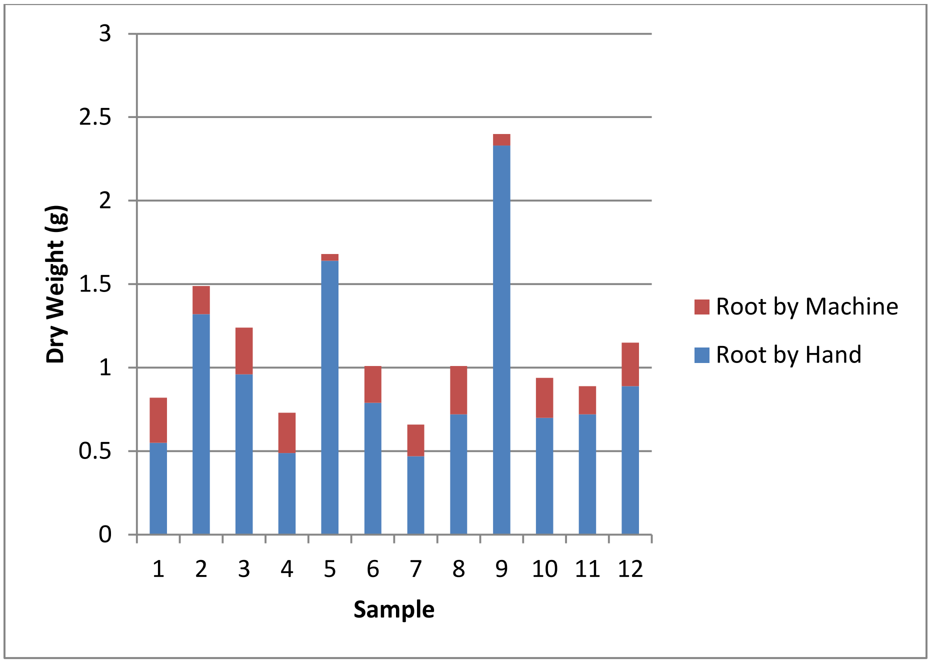

Figure 4.10: Hand washing method compared to retention of new machine wash

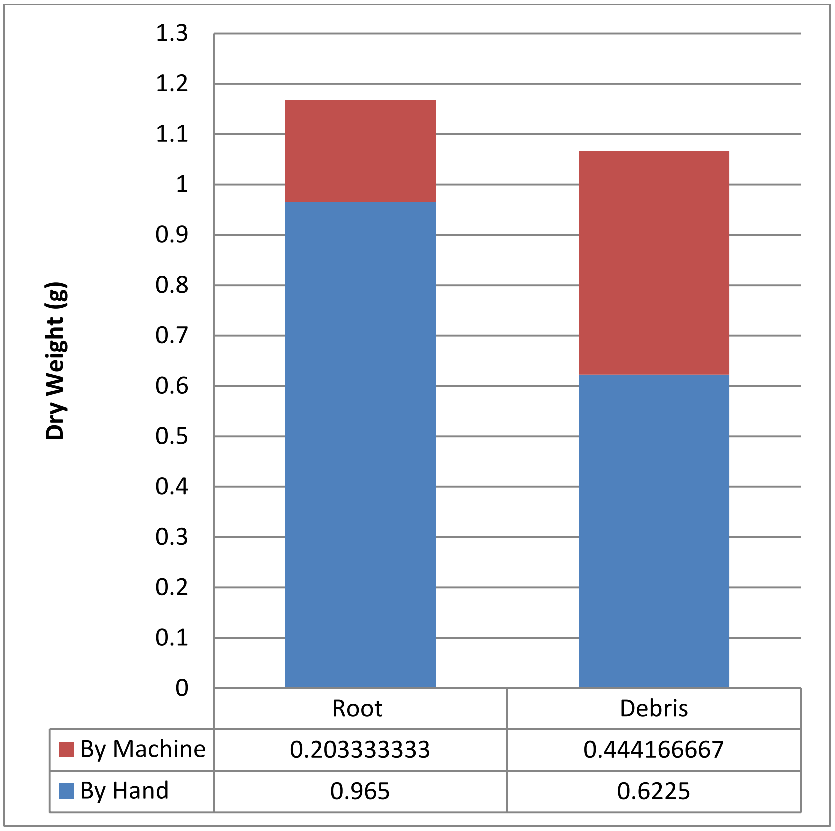

Figure 4.11: Average differences between hand and new machine wash methods

The new design for a root washing process proved a great success for the root samples collected and research for which it was designed. The design was inexpensive, repeatable, efficient, and water conservative. Construction of the device was done in house and assembly after clean out required less than 5 minutes. Sample processing requires one person to run the machine and switch samples.

Despite the many advantages of the new process there are also some downsides. One disadvantage of the new sample washing method includes variability between positions on the wash rack. The variability associated with each position has to do with the proximity of jets to the samples. Mesh bags can also be problematic. Picking roots out of the hems takes more time than cleaning sieves. Another inconvenience is using a stilling basin. Using gravity to move water into the holding tank and then pumping water out of the tank using the whirlpool pump can cause over flowing in the tub if settings are not correct or the operator is not familiar with the method. Reaching a sample processing time of 9.2 minutes per sample requires 15 samples to be run at the same time. For our research, which contained 108 samples, running 15 samples at a time was not an issue; however, in a small project with just a few samples per sampling event, the process time per sample would quickly increase.

4.5.2 Soil Sample Processing

4.5.2.1 Nutrient Analysis

Nutrient samples were taken with a spade to a depth of 15 cm, for out of track locations only, resulting in one sample per plot or 72 samples total. Samples were shipped to a commercial soils lab after air drying and preprocessing through a soil grinder. Nutrients and properties analyzed were OM, P-weak, P-strong, K, Mg, Ca, pH, CEC, NO_3^-, S, Zn, Mn, Fe, Cu, and B.

4.5.2.2 Particle Size Analysis

Particle size analysis was performed on out of track samples. A mechanical sieve analysis coupled with a hydrometer analysis was used to create particle distribution curves. A wet sieving method was used for years 2011 and 2012 due to inconsistencies among 2010 results because of clay content and aggregates of clay. Wet sieving was chosen based on the high clay content present at the two locations. For wet sieving, the soil sample was washed through a #200 sieve. Sample sizes were less than 500 g of soil as recommended by according to the largest particle size. Washed soil not passing through the #200 sieve was then dried and processed through a sieve stack of #4, #10, #40, #140, and #200. Washed soil and water passing through the #200 sieve in the first washing was collected, oven dried at 100°C for 24 hours to reduce the volume of water. The smaller than #200 sieve soil sample was then analyzed using a hydrometer analysis to find the fine-grained distribution of the soil. These methods are detailed by Sheldrick and Wang (1993).

4.6 Data Analysis

4.6.1 Means Analysis and Box Plot Creation

Means, standard deviations, and sample size were calculated and reported using SAS 9.2 statistical software, specifically proc means. Box plots were also created using SAS 9.2, proc sgpanel. Sample code to produce these outputs is given in Section A.3. When looking at the box plots, the 25th and 75th percentile are represented by the top and bottom of the vertical box. The mean is represented by the diamond inside the box. The horizontal line within the box represents the median and the vertical lines, whiskers, extend to the maximum and minimum values denoted by perpendicular, horizontal lines outside the box. Circles outside the extent of the whiskers are deemed “outliers”; extreme values considered very far from the mean.

4.6.2 Model Selection

Limitations in choosing sites and block layouts forced the experimental design. The data collection effort was centered on logistics of long distance travel, nine hours to sites, and being removed from immediate laboratory accessibility. While the experimental design, data collection, and externalities surrounding this study do not conform to a rigid statistical design, there existed methods to still make meaningful inferences about data collected by implementing model selection. Models are useful to represent the question at hand because of the parameters within the model and the connections between and among the variables. Data analysis will be focused on distributions of the data with box plots and constructing a meaningful model in order to assess which fixed effects and continuous variables most accurately described the observed biomass measurements.

Over and under fitting the best model was of great concern. The final completed dataset contained 80 variables. A suite of model variables were selected according to which variables were expected to describe the observations and variability in this data. These selections were based on literature reviews, discussions with colleagues and personal past experience and included a variety of fixed effects, random effects, and continuous variables. The model was not designed to predict belowground biomass but rather to explain abnormalities and variability in the data.

Non-nested model comparison was one reason for choosing an information criterion for comparing candidate models. Hypothesis testing only works when comparing nested models. Nested models are models including the same variables. Issues with unbalanced data were another reason for not using traditional hypothesis testing for choosing a model. Akaike (1981) argued hypothesis testing too often can be a poor approach to model selection. There exists no rigorous method for using the many P-values, which may be of varying power, to select a model; not to mention choosing an arbitrary alpha value that the model is highly dependent on (Burnham and Anderson, 2002).

For the purposes of finding the best model possible, the corrected Akaike information criterion (AICc) was used to compare a set of candidate models. Due to limited sample size, the final model was susceptible to over fitting if AIC (uncorrected) was used. As sample size increases AICc converges to AIC, so AICc should be used regardless of sample size.

The entire analysis and graphics for this document were generated using SAS/STAT software as well as SAS/GRAPH software, Version 9.2 of the SAS System for Windows.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Descriptive Statistics of Results

Introduction of parameters, associated distributions, and descriptive statistics are outlined as those parameters were introduced to the model during the model selection portion of the analysis. Additional figures, data, and code can be found in Appendix A and B. Biomass samples were taken from 2010-2012 at the two study sites. Nine treatment plots were sampled with three replications at each location. The plots consisted of training impacts (light, light with one year of recovery, light with subsequent light, and control) and land management treatments (hayed, burned, and control) for 2011-2012. This section summarizes the data by sampling year, site, block, and treatment. Additionally, descriptive variables are summarized in this section in order to help describe study results.

5.1.1 Belowground Biomass Dataset

There was one lost belowground biomass sample, EE 3-7 in track. Only one outlier was identified in 2011 and 2012. These points were left in the analysis because the scanned images showed very large roots; due to an adjacent sumac shrub in one sample and the nature of a bunchgrass like a *Sporobolus R. Br.*, dropseed, species in the other. Data that does not match the general mean of other data should not be cause for dropping these points from the dataset. Shrubs and bunchgrasses are common in tallgrass prairies so data having large diameter root masses should be left in the model so as to account for the occasional patch of these species and the uncertainty of encountering points like these in reality. Other samples did not reflect this occurrence due to the nature of surrounding plants when only plant is to be sampled. Figure 5.1 contains the images of the two samples side by side; plot EE 4-3 (out of track) 2011 on the left was recorded as a *Sporobolus R. Br.* and BB 2-1 (out of track) 2012 on the right was recorded as

Andropogon gerardii, big bluestem, but contains some roots believed to have come from a *Rhus glabra*, smooth sumac, shrub. Figure 5.1 below contains the roots scans and Figure 5.2 shows the pictures taken adjacent to the belowground biomass sample location. Aboveground images depict the effect of fire on litter and new biomass. The pictures also suggest a shrub such as sumac was burned off by the wildfire and the belowground biomass remained after burning took place.

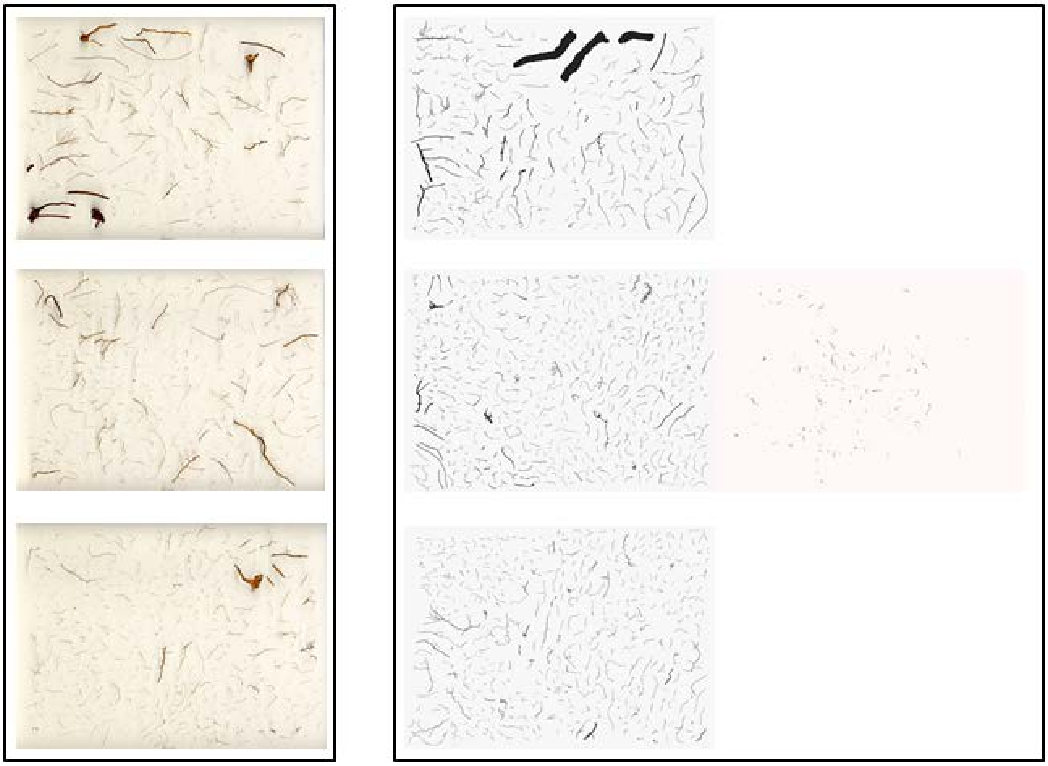

Figure 5.1: Two outlying belowground biomass points plotted side by side EE4-3 out 2011 (left) and BB2-1 out 2012 (right)

Figure 5.2: Pictures of aboveground biomass for plots EE4-3 out 2011 (left) and BB2-1 out 2012 (right)

5.1.2 Year Effect on Observations

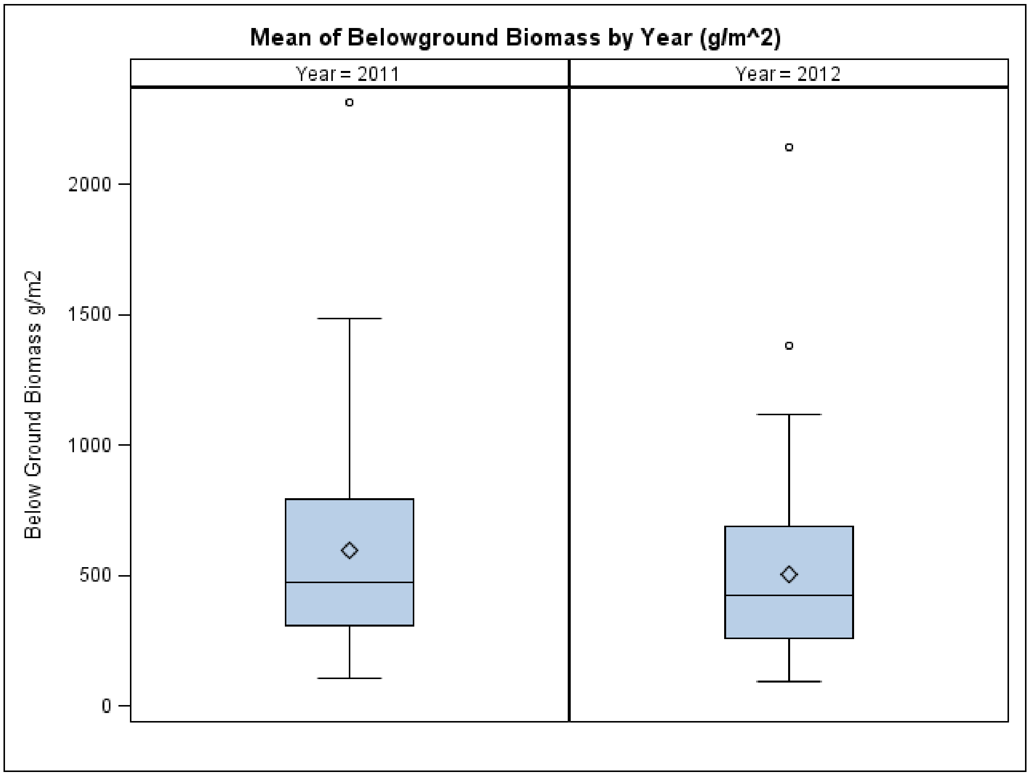

Figure 5.3: Effect of year on observed belowground biomass

The belowground biomass means show year 2012 having a slightly lower average belowground biomass than in 2011. Average belowground biomass for 2011 was 593.28 g/m^2 with a standard deviation of 407.17 g/m^2 and sample size of 53. The following year (2012) had an average belowground biomass of 502.32 g/m^2 with a standard deviation of 362.43 g/m^2 with a sample size of 54. Treatment applications and year-to-year weather variations can cause differences in biomass from one year to the next. In 2012, the additional Light + Light tracking occurred which could reduce the overall biomass average in 2012.

Climatic differences between 2011 and 2012 can be seen in both growing degree days (GDD) and precipitation. GDDs averaged 2435 in 2011 and 3007 in 2012 up to the dates that sample collection took place. GDDs were calculated based on methods presented by Frank et al. (1993). A base of 4.44°C (40°F) was used to make calculations, but GDD started accumulating only when GDD was positive for five consecutive days. The start date for GDD was also adopted for the initial condition for calculating cumulative precipitation. Cumulative precipitation was 39.17 cm in 2011 and 26.19 cm in 2012 up to the date samples were collected.

Reductions in rainfall have primarily been linked to decreases in aboveground biomass (Oomes and Mooi, 1981; Pandey and Singh, 1992; Silvertown et al., 1994; Holub, 2002; Lane et al., 2000); however, the effects of precipitation on belowground are unclear. Figure 5.4 depicts the differences in aboveground biomass by year. The mean aboveground biomass for 2011 was 439.97 g/m^2 with a standard deviation of 392.74 g/m^2 with a sample size of 54. 2012 mean aboveground biomass was 295.18 g/m^2 with a standard deviation of 267.74 g/m^2 with a sample size of 54. Ibrahim et al. (1997), Bakker et al. (2006), Fiala et al. (2009), and Qaderi et al. (2006) found belowground biomass was positively correlated with amount of moisture while Hayes and Seastedt (1987), Andrzejewska (1991), and Peek et al. (2006) found the opposite to be true.

These mixed findings suggest development of threshold values for root death. If soil moisture is lacking too much, roots will die. If soil moisture is in too much excess, root growth is not necessary to extract necessary water.

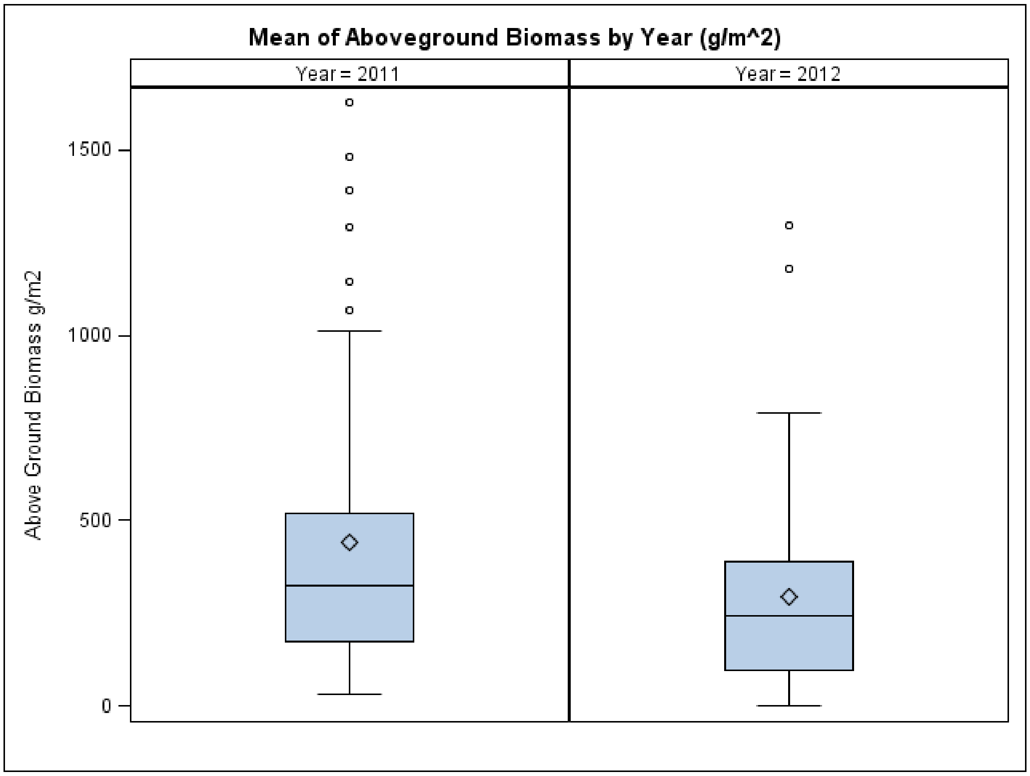

Figure 5.4: Effect of year on observed aboveground biomass

5.1.3 Site Effect on Observations

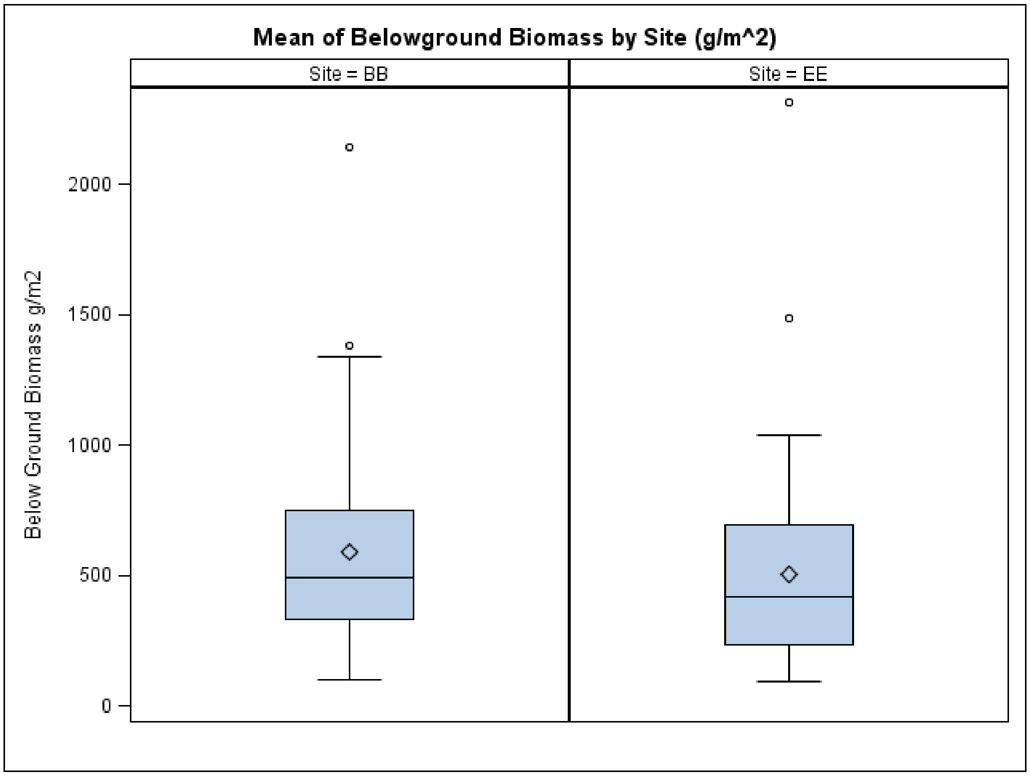

Figure 5.5: Differences in belowground biomass by site

Mean belowground biomass at site BB was 588.33 g/m^2 with a standard deviation of 380.12 and a sample size of 54. At the EE site, mean belowground biomass was 505.64 g/m^2 with a standard deviation of 391.32 and a sample size of 53. Characteristics specific to each site that could cause differences in the observed biomass could be soil types, available moisture, species composition, or treatment application. The BB site is dominated by a moderately well drained, silty clay loam and so is the EE site (Soil Survey Staff). The soil particle size distribution may not be significantly different, but upon visual inspection the EE site had higher moisture holding capacity. This observation was supported by TDR soil moisture readings (Figure 5.6). Volumetric moisture had a mean of 33.91% at the BB site and a mean of 38.87% at the EE site. Hui and Jackson 2005 found a negative correlation between moisture and the proportion of net belowground biomass compared to total net primary production existed when looking at a large collection of field measurements from grasslands. Essentially in wetter conditions, the plant is not required to allocate as much of its energy to obtaining moisture through rooting structures.

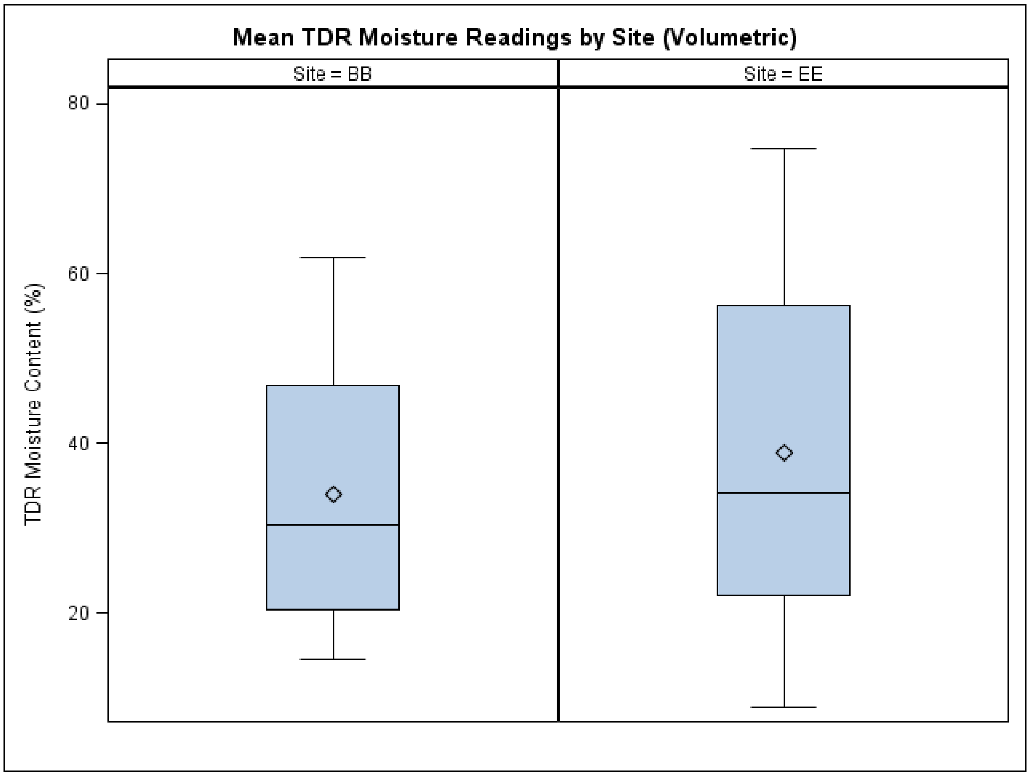

Figure 5.6: TDR moisture differences between sites BB and EE

Species composition was comparable between the two sites, but trafficking treatments varied greatly during the 2012 treatment. Moisture levels were very different in the spring of 2012. A wildfire impacted plots at the BB site earlier in the spring, removing all vegetation and creating a drier soil surface. At the time of the tank impacts, the soil moisture at the BB site was only 27.10% compared to 31.85% at the EE site on a volumetric basis with a sample size of 18 for each site. Figure 5.7 illustrates the differences in soil condition during the 2012 vehicle impacts. These soil moisture measurements were taken with only an hour separation.

Figure 5.7: Side by side comparison of tank destruction by site, BB (Left) and EE (Right)

5.1.4 Block Effect on Observations

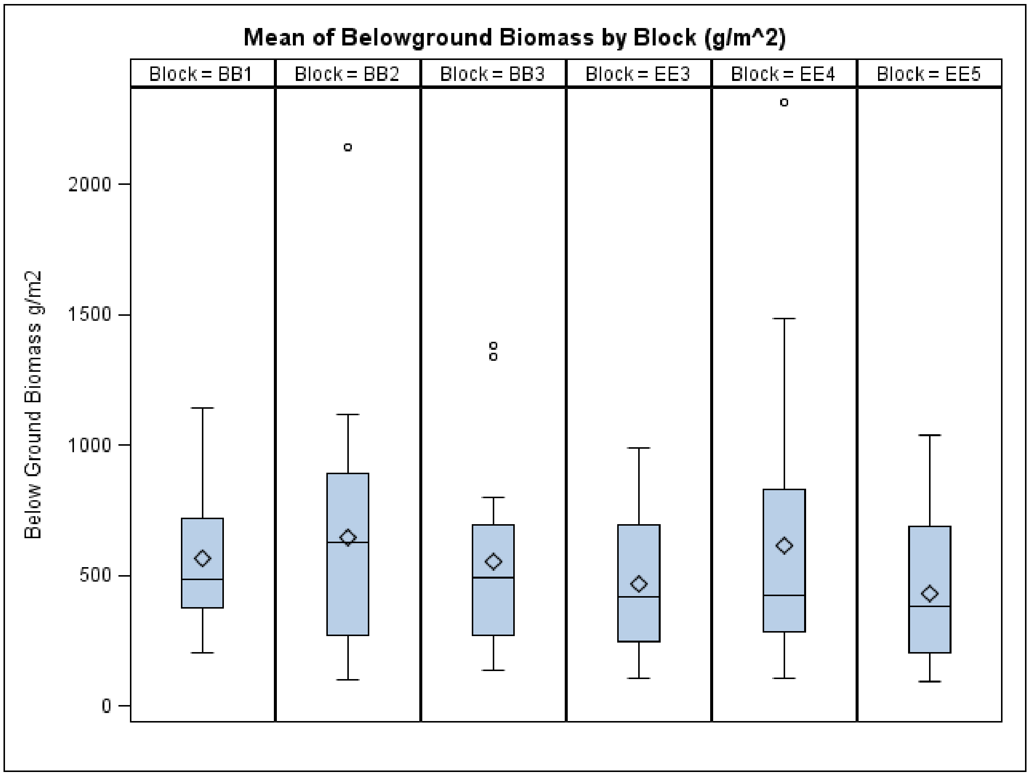

Figure 5.8: Effect of block on belowground biomass

The effect of block is less obvious because climate should be described by year while soils and vegetation communities should be described by site. Variability associated with each block could be linked to residual effects from historic military impacts and previous experimental impacts conducted in 2009. Means, standard deviations, and sample sizes of each block are included in the Table 5.1.

Table 5.1: Belowground biomass means by block

Block	Mean Belowground Biomass (g/m^2)	Standard Deviation	Sample Size
BB1	565.21	257.99	18
BB2	646.93	498.42	18
BB3	552.86	360.51	18
EE3	468.37	283.41	17
EE4	614.30	542.62	18
EE5	432.19	280.66	18

5.1.5 Treatment Effect on Observations

5.1.5.1 Land Management Practice

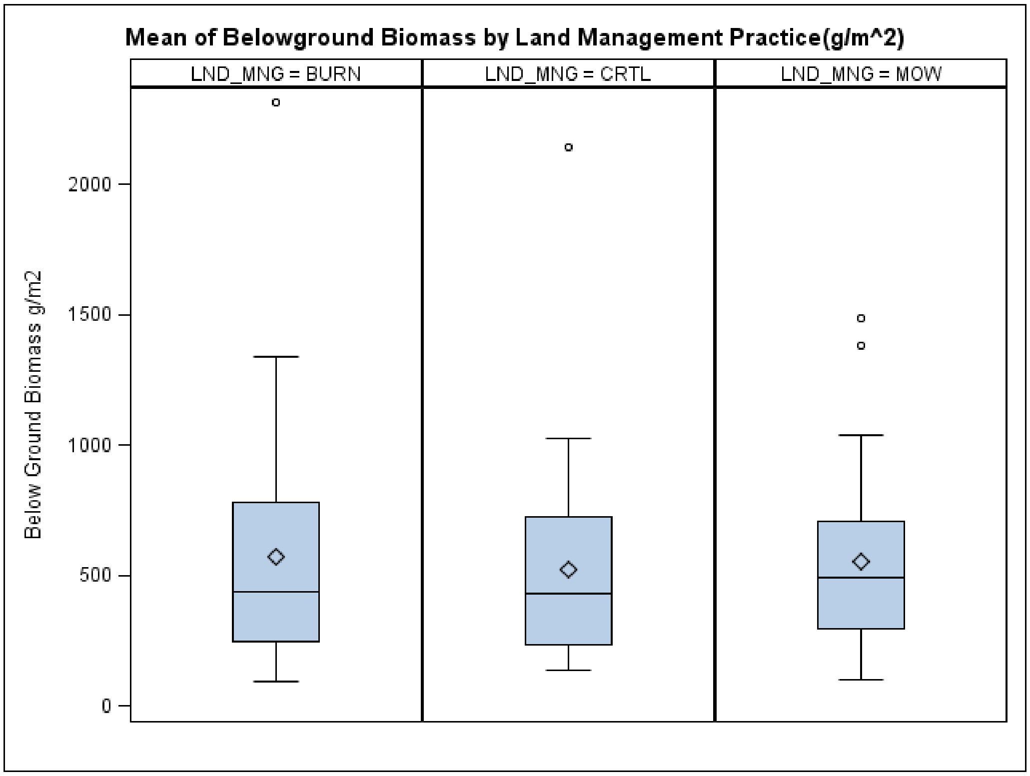

Figure 5.9: Effect of land management practices on belowground biomass

The impact of land management on belowground biomass is not significantly apparent after only two years of observations. The effect of burning was found to have a mean belowground biomass of 570.69 g/m^2 with a standard deviation of 443.40 g/m^2 with a sample size of 36. The control, no haying or burning treatments, was found to have a mean of 520.28 g/m^2, a standard deviation of 390.17 g/m^2 with a sample size of 35. Mowing was found to have a mean of 550.40 g/m^2, a standard deviation of 325.20 g/m^2 with a sample size of 36. These means included tracked treatments in the sample. Exogenous disturbances, e.g. land management, can require years of implementation to produce noticeable effects. Kitchen et al. (2008) reported a

48% increase in belowground biomass when burning took place and no net change when only mowing took place; however, this experiment was carried out over 13 years. Responses of root biomass to frequent burning have generally been increases in mass per area (Garcia, 1992; Benning, 1993; Johnson and Matchett, 2001; Kucera and Dahlman, 1968; Steastedt and Ramundo, 1990). Hayes and Seastedt (1987) found that similar rates of root loss were comparable between plots that were burned and unburned. Seastedt and Ramundo (1990) accounted the same rates of root disappearance and increases in biomass to overall greater rates of production. Mowing and burning have similar effects on belowground biomass by reducing N content in the roots (Turner et al., 1993; Blair, 1997). Mowing has also been proven to increase total root mass in unburned plots (Benning and Seastedt, 1997; Dickinson and Polwart, 1982).

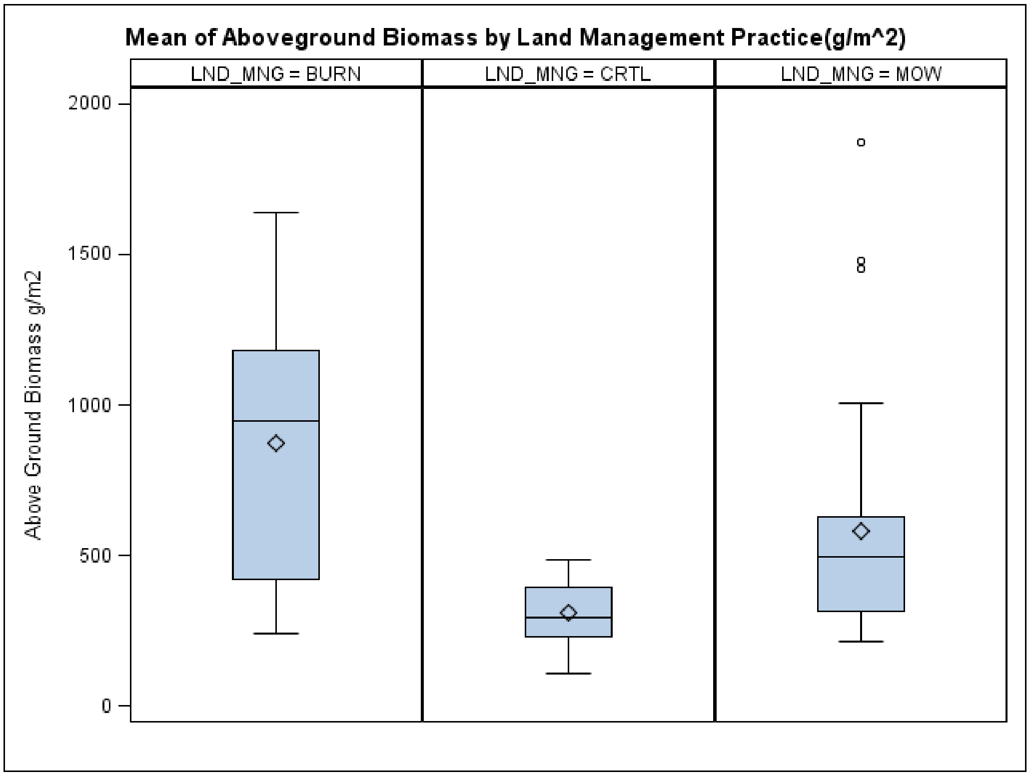

Figure 5.10: The effect of land management practices on aboveground biomass

Aboveground biomass production is highly dependent on shading due to detritus accumulation (Hulbert, 1969; Rice and Parenti, 1978; Towne and Owensby, 1984; Knapp and Seastedt, 1986). Previous year's dead biomass can reach 1,000g/m^2 and reaches equilibrium after three years (Weaver and Rowland, 1952). Fire and mowing have similar effects on the amount of dead biomass at the surface. Removal of this litter allows more light interception when new shoots are emerging. This effect is seen in the differences between aboveground biomass means based on land management practices. When burning takes place a mean of 543.83 g/m^2 was observed with a standard deviation of 456.24 g/m^2 with a sample size of 36. The control was found to have a mean of 214.65 g/m^2 with a standard deviation of 113.98 g/m^2 with a sample size of 36. Following mowing and raking, a mean of 344.24 g/m^2 was observed with a standard deviation of 283.89 g/m^2 with sample size of 36. After reviewing studies spanning 50 years, Risser et al. (1981) concluded that fire increased aboveground net primary production (ANPP) when moisture was adequate, but results were highly variable. During years when moisture a shortage of moisture is present, burning removing aboveground, detritus biomass causing soils to dry easier. Soil moisture levels then fall below levels necessary for optimal growth. At some sites a reduction of over 50% was observed but also sites saw a fourfold increase compared to areas protected from fire. Generalizations are hard to make about one practice compared to another but it should be noted that ANPP is bounded by moisture and nitrogen limitations (Owensby et al., 1969).

5.1.5.2 Traffic Level

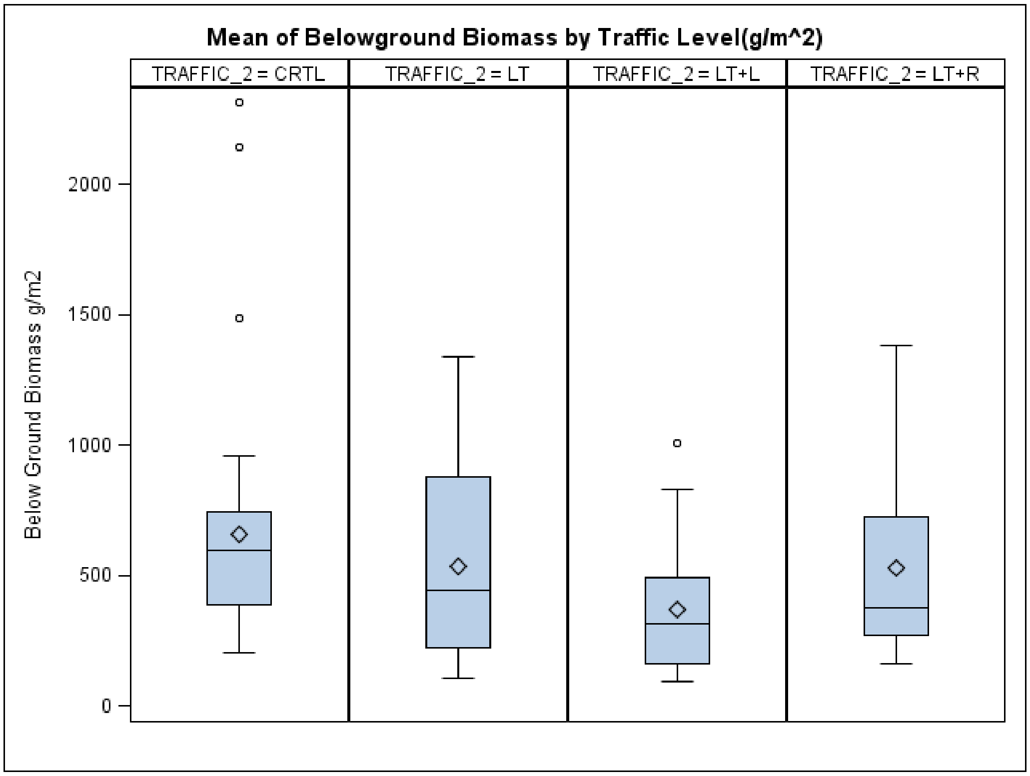

Figure 5.11: The effect of military trafficking on belowground biomass

A summary of the trafficking effects on belowground biomass are given in the Figure 5.11 and Table 5.2. Little research has been done to understand the effects of tracked vehicle training on belowground biomass (Guretzky et al., 2005). While no direct causes can be cited from the literature, many inferences can be made based on effects of trafficking on soil properties and aboveground biomass removal.

Table 5.2: Belowground biomass means by trafficking

Traffic Intensity	Mean Belowground Biomass (g/m^2)	Standard Deviation	Sample Size
Control (CRTL)	657.48	459.80	36
Light (LT)	534.25	342.91	35

Table 5.2 (cont.): Belowground biomass means by trafficking

Traffic Intensity	Mean Belowground Biomass (g/m^2)	Standard Deviation	Sample Size
Light + Recovery (LT + R)	528.46	365.35	18
Light + Light (LT + L)	371.60	258.07	18

Bulk density has been shown to be significantly increased due to military training (Braunack, 1986; Althoff et al., 2006; Prosser et al., 2000). Bulk density is affected in different ways based on moisture content (Halvorson et al., 2001; Thurow et al., 1993), number of passes (Braunack and Williams, 1993; Grantham et al., 2001), and turning radius (Ayers, 1994). When bulk density increases and soil hardness increases, the negative effects on root growth are significant and hinder plant growth (Passioura, 2002). Bulk density by traffic level are depicted in the Figure 5.12 and detailed in Table 5.3.

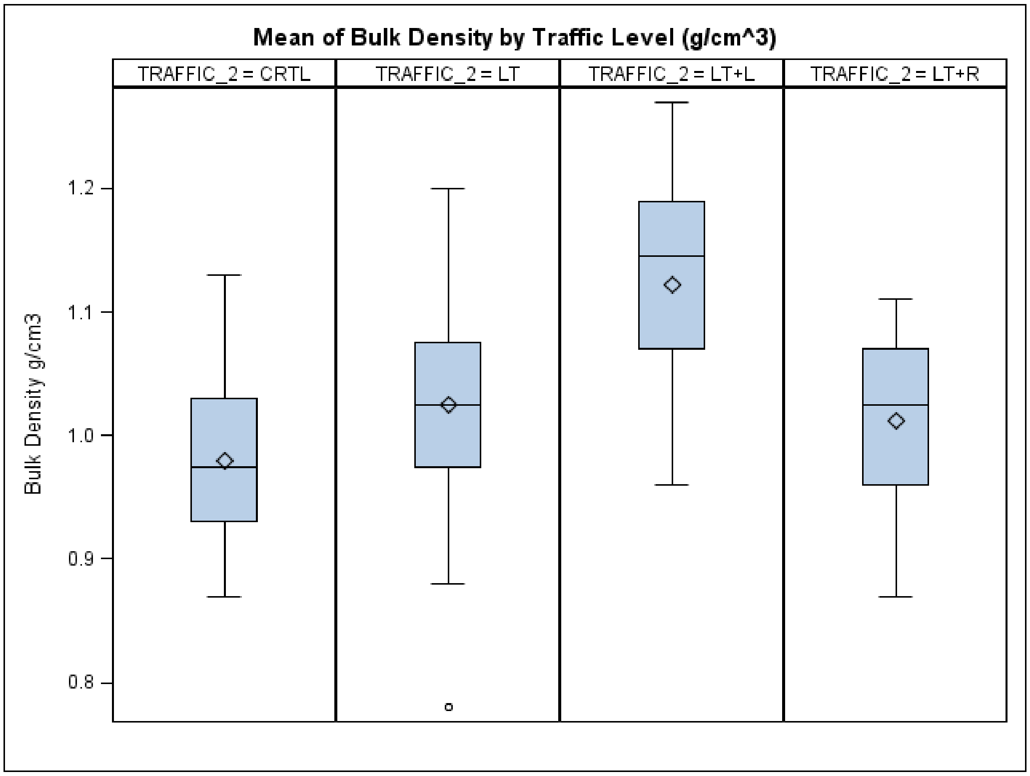

Figure 5.12: Effect of trafficking on bulk density

Table 5.3: Means of trafficking effect of bulk density

Traffic Intensity	Mean Bulk Density (g/cm^3)	Standard Deviation	Sample Size
Control (CRTL)	0.98	0.063	36
Light (LT)	1.02	0.081	36
Light + Recovery (LT + R)	1.01	0.071	18
Light + Light (LT + L)	1.12	0.089	18

The correlation between soil hardness and root growth can be represented by cone penetration resistance (Passioura, 1991). Root growth has been shown to drastically slow once penetration resistance exceeds 1,000 kPa and almost ceases at 5,000 kPa (Bengough and Mullins, 1990; Materechera et al., 1991). It should be noted that there are confounding effects as roots increase soil penetration resistance by removing moisture, a self-reinforcing process (Bengough, 1997). The correlation matrix (Figure 5.15) illustrates the positive correlation between belowground biomass presence and penetration resistance.

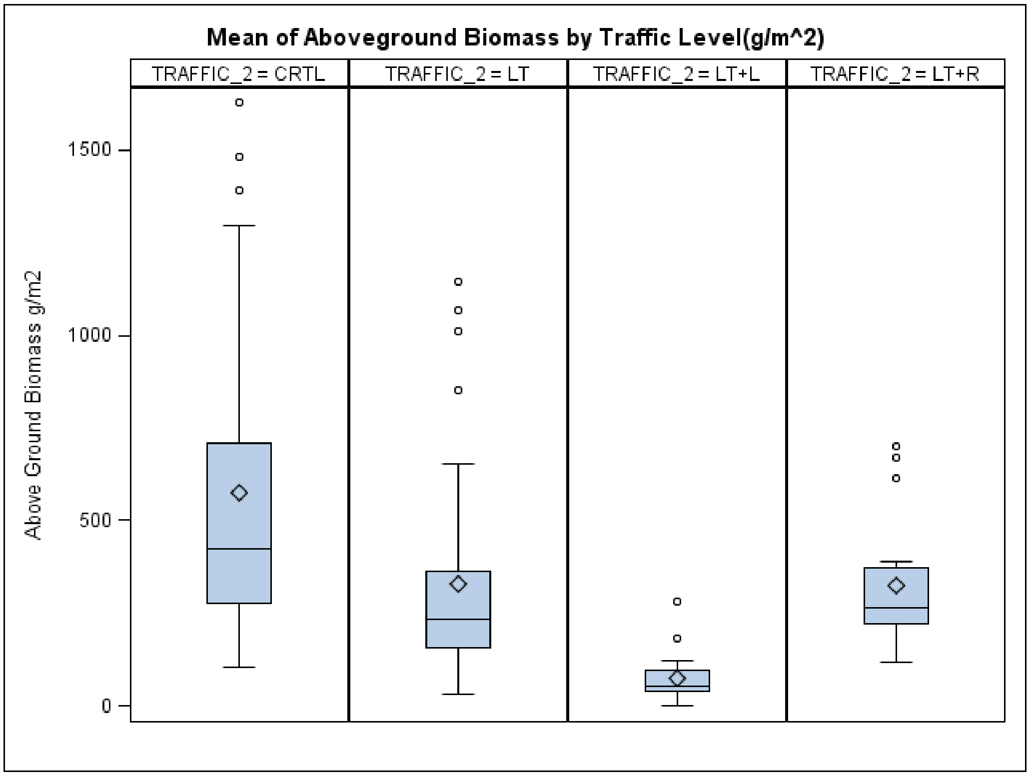

Figure 5.13: Effect of military trafficking on aboveground biomass

Samples were taken on vehicle turns in all plots. Anderson et al. (2007) found that vegetation removal rates were higher during turning maneuvers compared to straight-line tracking. Carrying capacity models typically use straight-line tracking as the basis for vegetation removal. Haugen et al. (2003) found that approximately 16% of vehicle tracking during training exercises occurred at radii less than the critical radii determined by Anderson et al. (2007). Thus, carrying capacity models potentially over estimate land carrying capacity. This study considers the worst case scenario as samples were collected at the sharpest point along the turn.

Destroying or removing vegetation reduces the leaf area index (LAI), reducing the photosynthetic capacity and therefore, plant growth (Briske, 1991). Sustenance for new aboveground growth must come from remobilized carbon found in the root portion, causing increased root death and reduced root growth (Briske, 1991). Unpublished results from a scraping study have shown that a heavy impact with no land management causes a 45% reduction in belowground biomass in a shortgrass prairie (Williams and Munns, 1979). The impact of military vehicles on aboveground biomass in this study can be seen in the averages of the collected biomass in the Table 5.4.

Table 5.4: Aboveground biomass means by trafficking

Traffic Intensity	Mean Aboveground Biomass (g/m^2)	Standard Deviation	Sample Size
Control (CRTL)	575.08	412.82	36
Light (LT)	327.63	284.07	36
Light + Recovery (LT + R)	325.42	170.11	18
Light + Light (LT + L)	74.63	66.61	18

5.1.5.3 Treatment Interaction

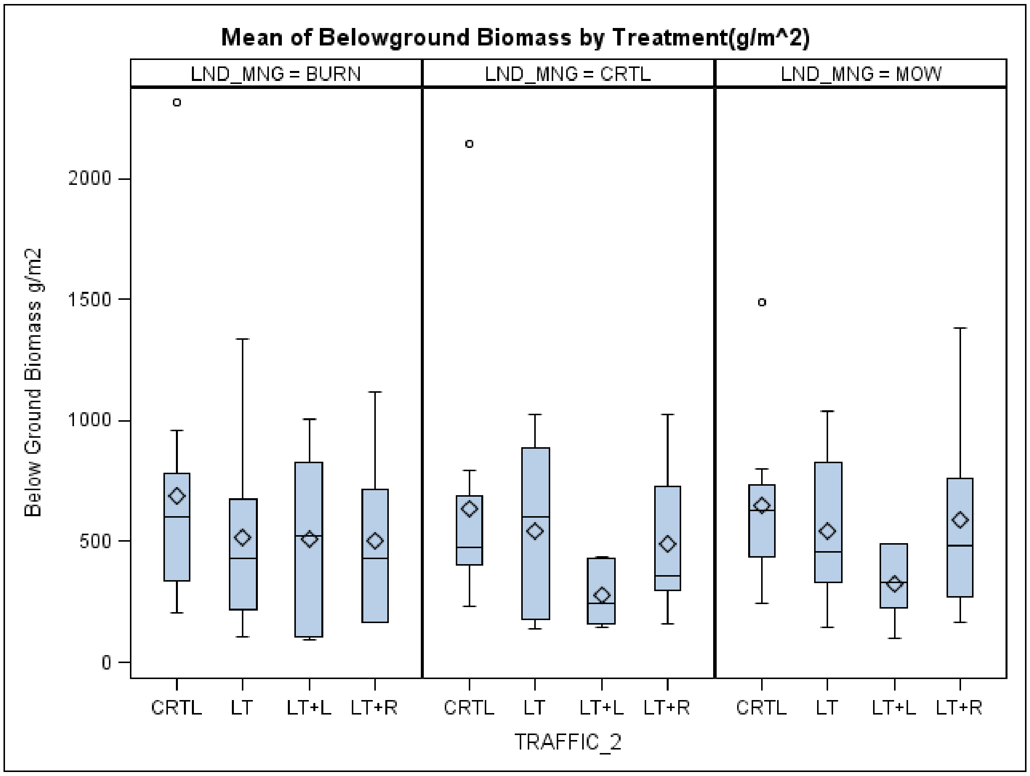

Figure 5.14: Effect of treatment interaction on belowground biomass

Table 5.5: Belowground biomass means by treatment interaction

TRAFF	LND	Mean Belowground Biomass (g/m^2)	Standard Deviation	Sample Size
CRTL	CRTL	636.36	504.46	12
CRTL	MOW	646.66	315.26	12
CRTL	BURN	689.43	563.12	12
LT	CRTL	544.34	351.58	11
LT	MOW	545.46	305.20	12
LT	BURN	513.79	396.53	12
LT+R	CRTL	488.70	324.01	6

Table 5.5 (cont.): Belowground biomass means by treatment interaction

TRAFF	LND	Mean Belowground Biomass (g/m^2)	Standard Deviation	Sample Size
LT+R	MOW	591.54	456.21	6
LT+R	BURN	505.15	365.24	6
LT+LT	CRTL	275.61	128.47	6
LT+LT	MOW	326.62	155.46	6
LT+LT	BURN	512.55	385.28	6

The most notable thing to mention about the interactions is the positive effect burning had on belowground biomass after the second consecutive trafficking event in 2012, LT+LT. Burning and mowing plots were noticeably drier, based on observations of the tank drivers. Removal of vegetative cover increased evaporation and defoliation increased aboveground production resulting in increased transpiration. Drier plots coincidentally yielded less destruction and increases in biomass production in the heavily impacted plots.

5.1.6 Covariates

After adding climate and location variables as well as fixed treatment effects, covariates were deemed necessary to help explain variability in the observed belowground biomass. A correlation matrix depicted the scatter plot of data of above variables, Figure 5.15 and Figure 5.16. The Pearson's product-moment showed the same variables to be significantly correlated with belowground biomass; those variables were bulk density, 0-6 in penetrometer, 6-12 in penetrometer, aboveground biomass, individual plant dry weight, percent live ground cover, proportion of cover considered grass, and proportion considered forbs. These variables were chosen based on the Pearson's product-moment coefficient, ρ. This approach is not used to identify significant variables, but rather choose from variables known to have an impact on or be impacted by belowground biomass. The hypothesis used to choose these variables as being correlated is given below. An alpha of 0.05 was used.

$$H_o: \rho = 0$$

$$H_a: \rho \neq 0$$

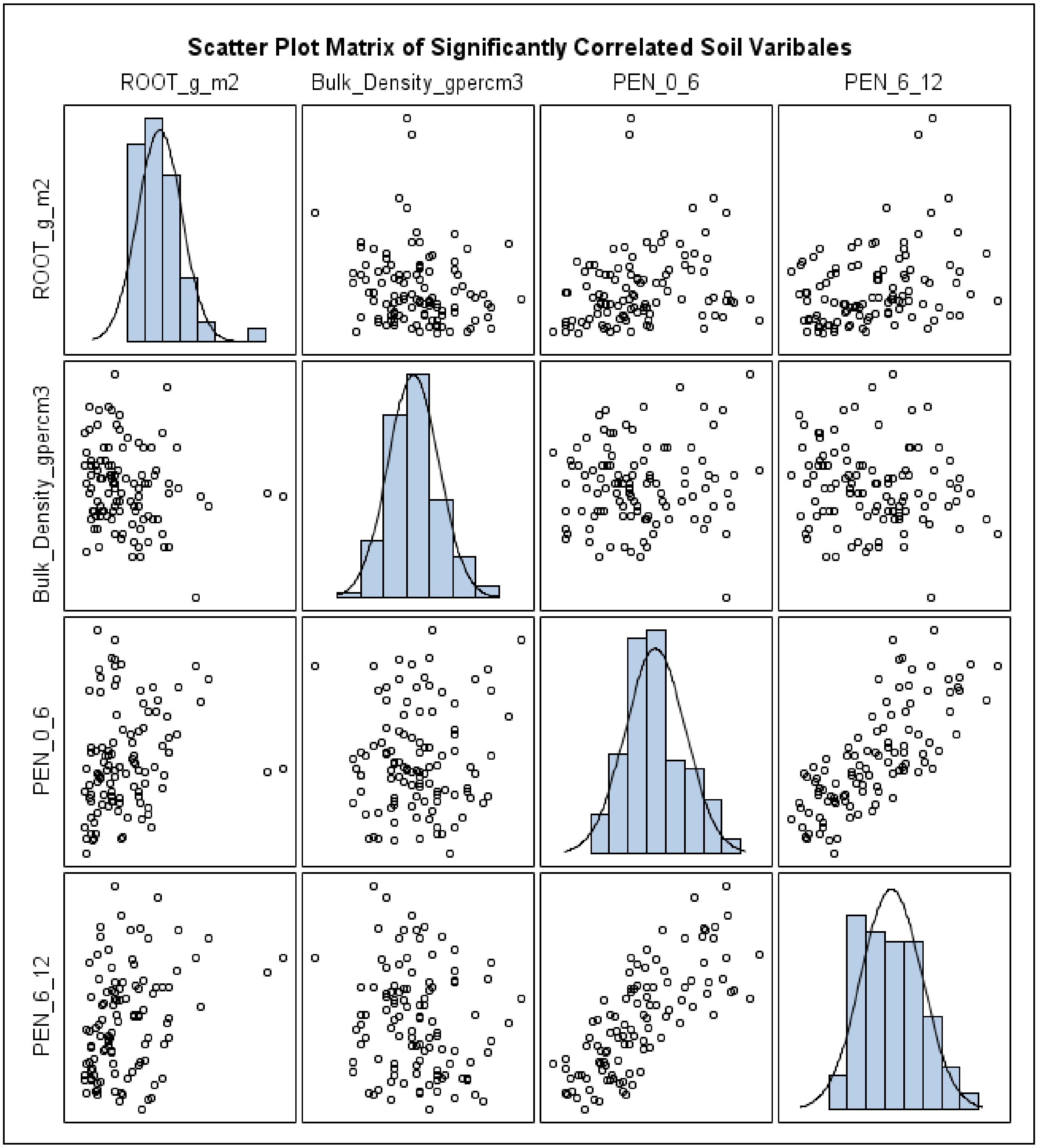

Figure 5.15: Scatter plot matrix of correlated soil variables with variable distributions

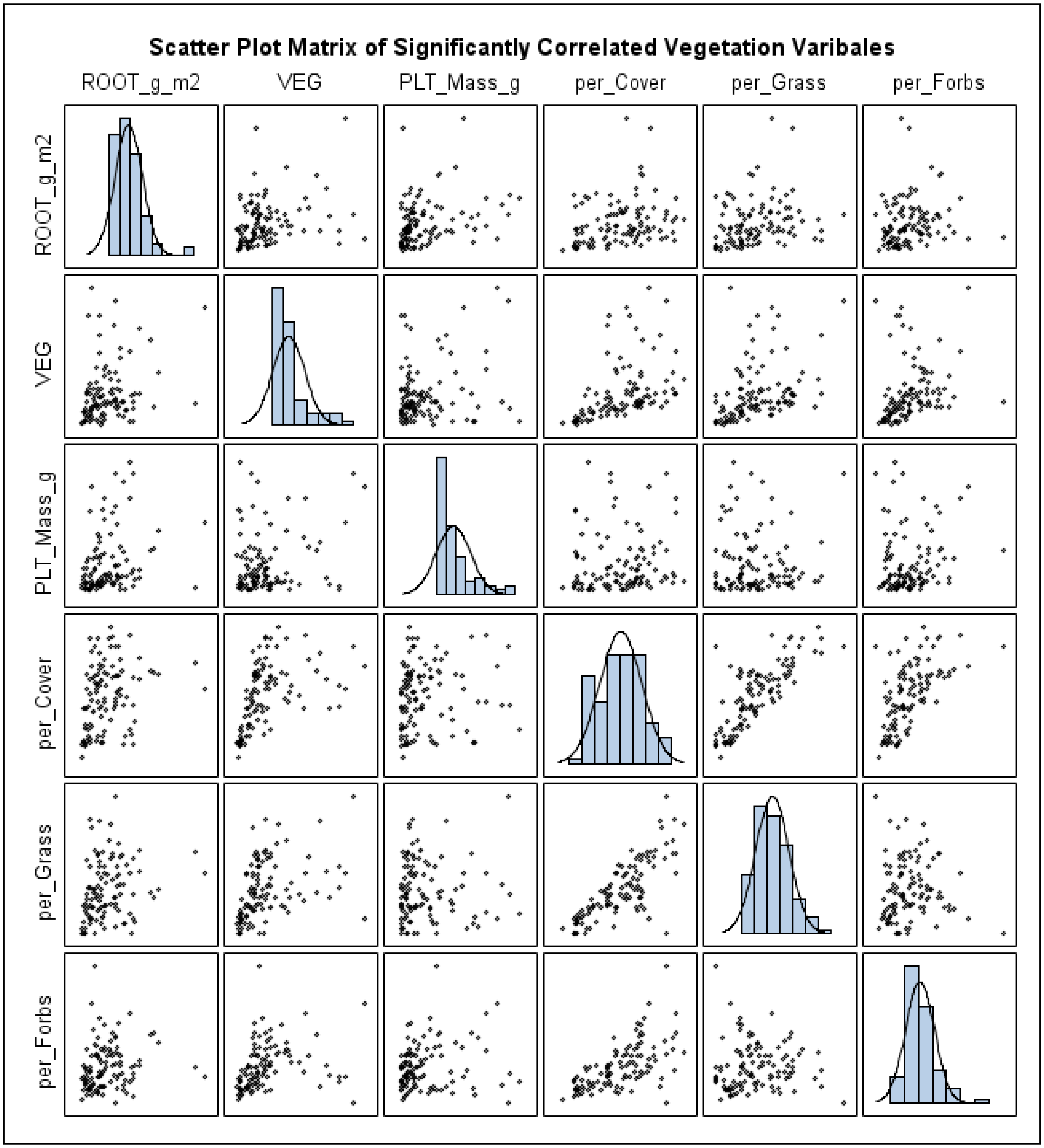

Figure 5.16: Scatter plot matrix of correlated vegetation variables with variable distributions

5.2 Model Selection

Possible combinations of random and fixed effects with continuous covariates are presented in Table 5.7. Candidate models are formulated based on knowledge of the parameters and their ability to describe variation in observed belowground biomass. Parameters are added and subtracted in a methodical manner, shown in Figure 5.16, to identify the most parsimonious model and then provide a foundation of inference. Candidate models are presented with parameter names, number of parameters, AICc, and difference in AICc in comparison to the smallest AICc found.

Information preservation was the basis for using AICc, based on the Kullback-Leibull divergence (Burnham and Anderson, 2002). The model which minimized the information lost when trying to describe belowground biomass, the left side of the model, had the lowest AICc. Parameters were initially included individually, to assess their separate ability to preserve information. Location, Year, and Site lost the most information. These variables were considered random and should not have performed well discretely, but improved upon models losing less information with fixed variables and covariates. As described in the land management, Section 5.1.5.1, the impact of LND on belowground biomass was unclear through two years of data and should lose more information than military trafficking, TRAFF.

Random Effects
Y (Year) – 2011, 2012
L (Site) – BB, EE
B (Block) – BB1, 2, 3 and EE3, 4, 5

Fixed Effects
LND (Land Management) – CRTL, MOW, BURN
TRAFF (Traffic Level) – CRTL, LT, LT + R, LT + LT

Covariates
VEG – Aboveground biomass (g/m^2)
PLT_Mass_g – Ind. plant dry weight (g)
PER_Cover - % Live ground cover
PER_Grass - % Live ground cover (grass)
PER_Forbs - % Live ground cover (forbs)
BD – Bulk density (g/cm^3)
PEN_0_6 – Penetrometer 0-15.24 cm
PEN_6_12 – Penetrometer 15.24-30.48 cm

Table 5.6: Candidate models

Model	Parameters					AICc	ΔAICc
1	B					1677	386.6
2	Y					1594.1	303.7
3	VEG					1532.2	241.8
4	L					1530	239.6
5	PEN_0_6					1525.7	235.3
6	PLT_Mass_g					1524.6	234.2
7	BD					1524	233.6
8	PER_Forbs					1520.1	229.7
9	LND					1519.9	229.5
10	PER_Grass					1518	227.6
11	PER_Cover					1515.6	225.2
12	PEN_6_12					1506.3	215.9
13	TRAFF					1500.8	210.4
14	TRAFF	LND				1479	188.6
15	B	TRAFF	LND			1614.4	324
16	Y	TRAFF	LND			1530.7	240.3
17	L	TRAFF	LND			1467.2	176.8
18	TRAFF	LND	TRAFF*LND			1401.5	111.1
19	B	TRAFF	LND	TRAFF*LND		1536.9	246.5
20	Y	L	TRAFF	LND		1518.9	228.5
21	Y	B	TRAFF	LND		1470.9	180.5
22	Y	TRAFF	LND	TRAFF*LND		1453.3	162.9
23	L	B	TRAFF	LND		1419	128.6
24	L	TRAFF	LND	TRAFF*LND		1389.8	99.4
25	L	TRAFF	LND	TRAFF*LND	PER_Forbs	1512.4	222
26	L	TRAFF	LND	TRAFF*LND	PEN_0_6	1511.8	221.4
27	L	TRAFF	LND	TRAFF*LND	PER_Grass	1502.2	211.8

Table 5.6 (cont.): Candidate models

Model	Parameters							AICc	ΔAICc
28	L	TRAFF	LND	TRAFF*LND	PER_Cover			1500.6	210.2
29	L	TRAFF	LND	TRAFF*LND	PEN_6_12			1488.4	198
30	Y	L	B	TRAFF	LND			1470.9	180.5
31	Y	L	TRAFF	LND	TRAFF*LND			1441.5	151.1
32	Y	B	TRAFF	LND	TRAFF*LND			1393.4	103
33	L	TRAFF	LND	TRAFF*LND	VEG			1384.1	93.7
34	L	TRAFF	LND	TRAFF*LND	BD			1374.9	84.5
35	L	TRAFF	LND	TRAFF*LND	PLT_Mass_g			1372.1	81.7
36	L	B	TRAFF	LND	TRAFF*LND			1341.5	51.1
37	L	B	TRAFF	LND	TRAFF*LND	PER_Forbs		1464.1	173.7
38	L	B	TRAFF	LND	TRAFF*LND	PEN_0_6		1461.4	171
39	L	B	TRAFF	LND	TRAFF*LND	PER_Grass		1453.8	163.4
40	L	B	TRAFF	LND	TRAFF*LND	PER_Cover		1452.2	161.8
41	L	B	TRAFF	LND	TRAFF*LND	PEN_6_12		1439.7	149.3
42	Y	L	B	TRAFF	LND	TRAFF*LND		1393.4	103
43	L	TRAFF	LND	TRAFF*LND	PEN_6_12	PER_Cover		1339	48.6
44	L	B	TRAFF	LND	TRAFF*LND	VEG		1334.6	44.2
45	L	B	TRAFF	LND	TRAFF*LND	BD		1326	35.6
46	L	B	TRAFF	LND	TRAFF*LND	PLT_Mass_g		1323.6	33.2
47	B	TRAFF	LND	TRAFF*LND	PEN_6_12	PER_Cover		1290.4	0
48	L	B	TRAFF	LND	TRAFF*LND	BD	PLT_Mass_g	1308.5	18.1
49	L	B	TRAFF	LND	TRAFF*LND	PEN_6_12	PER_Cover	1290.4	0

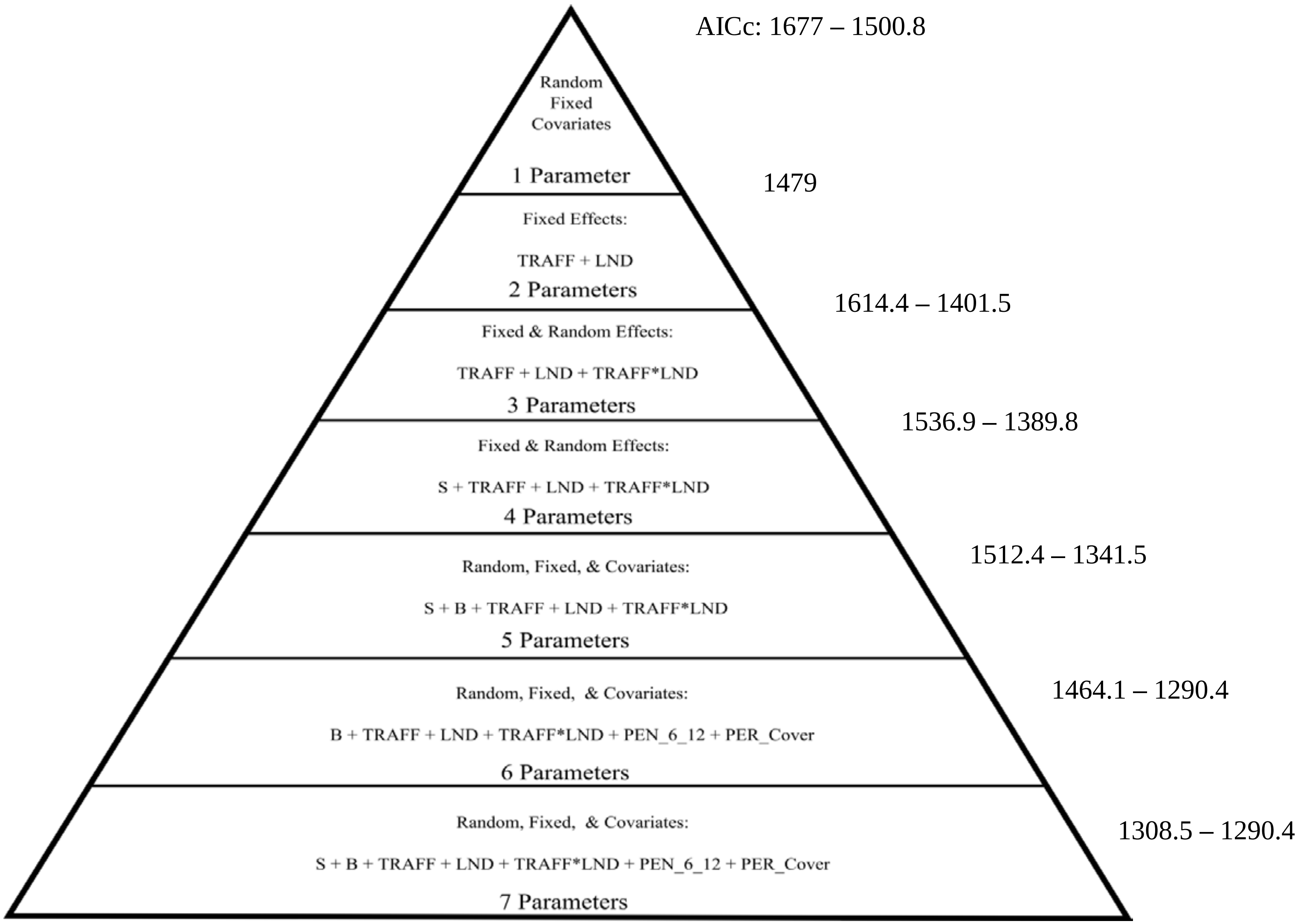

Figure 5.17: Pictorial description of how parameters were added to the model starting with the top including the range of AICc values for each step reported to the right (lowest AICc preserved most information)

Aboveground biomass measurements, VEG and PLT_Mass_g, were seen to have the smallest impact as a group. Soil strength parameters (BD, PEN_0_6, and PEN_6_12) tended to agree with findings presented in Section 5.1.5.2, because penetrometer was better at describing belowground biomass. The top 15.24 cm reading did not perform as well due to interference with the aboveground biomass, when taking readings.

The fixed effects were shown to be effective in describing belowground biomass response individually. Establishing their importance was the objective of this research. Together the fixed effects outperform any of the individual parameters; therefore, LND and TRAFF will be the base of all subsequent candidate models. The significance of land management and traffic intensity effect on belowground biomass agree with literature discussed in Sections 5.1.5.1 and 5.1.5.2. The only random variable that improved the model, with only the two fixed effects, was site. Since site adds a significant amount of information, it could be inferred that soil type and moisture have impact on the amount of belowground biomass observed. Therefore, site was kept in other candidate models. Adding multiple random variables did little to help except when location was added in conjunction with site. An interaction between TRAFF and LND was a significant addition to the two fixed effects as well. Thus far, the best model includes site, TRAFF, LND, and the interaction TRAFF*LND.

Covariates were added to the model deemed best thus far, to gain information about how belowground biomass varies with soil physical properties and aboveground biomass measurements. BD and the direct measurements of aboveground biomass, VEG and PLT_Mass_g, were seen to add the greatest amount of information to the model. These direct measurements were seen to add the most information, when added individually in models with site, as well as site and location included. Aboveground vegetation, individual plant dry weight, and bulk density were both proven in the literature to be useful measurements for estimating belowground biomass. PLT_Mass_g and BD were added to the model with site, location, LND, TRAFF, and LND*TRAFF with an AICc of 1308.5 observed. This model had the lowest AICc thus far, but other adjustments to more fitting parameters were made.

The two covariates that performed best, individually, were added to the model next. PEN_6_12 was found to have an AICc of 1506.3 and PER_Cover was found to have an AICc of 1515.6. Adding the two covariates to a model with site, location, LND, TRAFF, and LND*TRAFF yields the lowest AICc yet of 1290.4. PEN_6_12 has been proven to be correlated with belowground biomass in Section 5.1.5.2. Percent live cover has been known to correlate well with aboveground biomass (Paruelo et al., 2000; MacDonald, 2012) and live aboveground biomass has been proven an important parameter when estimating belowground biomass (Gill et al., 2002). A model with the lowest AICc may not be parsimonious; thus, the random parameters included are evaluated individually to assess effectiveness since all other parameters have been proven effective in the literature and by the data.

Site was removed from the model first. This parameter was least specific since it describes samples by dividing data points into two categories, EE or BB. After removing site, the same AICc was observed, 1290.4. Site was not preserving any additional information when being penalized for the increase in number of parameters. When only location was removed the AICc increased to 1339.0. Therefore the model including location, TRAFF, LND, TRAFF*LND, PEN_6_12, and PER_Cover was chosen as the best, because the addition of more parameters failed to improve the amount information gained, this model had a lower AICc.

The model chosen based on AICc and subject knowledge gives subsequent research a starting point as to which measurements should be considered paramount. First, data collection should revolve around describing block effects through treatment differences, pre-existing conditions, and natural variation. Land disturbance, whether it is through land management or military training, significantly affects vegetation physiology. The cone index, penetrometer reading, is a good indication of root growing ability. Percent live plant cover was also shown to effectively preserve information about belowground biomass.

Loss of experimental design did not hinder the extraction of useful information from this research. Loss of experimental design occurred when light treatments were done on eight plots per block the first year and heavy treatment was done on three plots per block the second year. Instead, treatments should have taken place as follows: three plots impacted with three round trip passes (light) and three plots per block impacted with six round trip passes (light + light) for both years. The latter design would have yielded balanced, equal replication and permitted the used of more rigid, traditional, statistical methods. The study carried out did give insight into recovery as well as impacts taking place on top of preexisting tracks. Wildfire also impacted the effect of land management treatments. Effects of wildfire could be compared to controlled burn in other research efforts; observed to be different based on dead litter present on the surface of controlled burn sites. All together these conditions imitate reality with wildfires affecting many areas of the installation even where other land management practices are being applied.

CHAPTER 6: CONCLUSIONS

A database was compiled with measurements related to soil physical properties, vegetation physiological properties, and many other measurements known to describe soil and overall ecosystem health. While only TRAFF, LND, TRAFF*LND, PEN_6_12, and PER_Cover were included in this analysis, these may be of importance to other researchers in the future looking at other questions involving military disturbance, land management, or the interactions between the treatments.

Results from this research, suggest that many other methods of root washing can be much more efficient than previously accepted hand washing techniques. The root washer developed for the purpose of this study was inexpensive, repeatable, efficient, and water conservative. Finer root mass was recovered using the new method of separation resulting in a more complete and less variable separation of root from soil. Increases in sample variability were necessary to show discernible differences between treatments. Methods of washing are suited for different situations and knowledge of variability and losses associated with each are essential when choosing a washing method.

For Objective 3, findings suggest after two years of treatment, land management techniques of burning and haying are beginning to stimulate below ground biomass compared with the control. Although the extent to which these practices were changing the amount of root mass was unclear; with high variability after two years of data collection. While the addition of land management parameters did significantly reduce the AICc value, this was not the sole reason for inclusion. Land management was included in the final model used to explain variability, because of evidence present in the literature; even if the effect took much longer to become significant. Military vehicular training disturbance, was found to have a significant impact on belowground biomass. As tracking intensity increased, a decrease in belowground and aboveground biomass was observed. Trafficking was included in the final model describing belowground biomass because of the obvious effects observed on root mass. This was reinforced in the final model, as the addition of the parameter significantly reduced the AICc value. The effect of the interaction between land management and traffic intensity on belowground biomass was also unclear due to the ambiguity of effects caused by land management practices. Burning lessened the effects of tank disturbance, most likely through increased evapotranspiration and lower amounts of litter covering the soil surface early in the growing season. The defoliation process increased aboveground biomass at the beginning of the growing season. This may have varying effectiveness due to timing of burns with respect to climate and training. The interaction was also included in the final model, not only because it was found to lower the AICc value, but also because the interaction of the two parameters were found to be significant belowground biomass production.

Covariates chosen to assist in explaining variation in belowground biomass were penetrometer readings, cone index, and percent live cover. Penetrometer has been shown to be well fitted for determining root restricting layers, describing traffickability and estimating belowground biomass (EP542, 1999; Passioura, 1991). Ground cover has also been researched as possible measure for determining aboveground vegetation, a measure used by Gill et al. (2002) to model belowground biomass in global grasslands. Percent live cover has also been studied as a means to estimate aboveground biomass; thus, this measure can be done through some form of remote sensing (Paruelo et al., 2000; MacDonald et al., 2012). A random effect of location, or block, was found to be a significant parameter when explaining belowground biomass.

This study is the beginning of an effort to understand the otherwise unknown interactions of military disturbance and land management practices on belowground biomass. Military training effects on belowground biomass, the portion of the plant necessary for recovery, have not been researched exclusively previous to this study. This study showed that light trafficking caused a 21% reduction in belowground biomass. Similarly, even with a year of recovery there was still a 22% reduction in belowground biomass. After two consecutive year of trafficking a 45% reduction in belowground biomass was observed. Land management practices have been researched in the past, but many report conflicting results. This study found fire and mowing to increase belowground biomass compared to the control by 10% and 4% respectively. The interaction of the two is of chief concern to military land mangers when determining training land carrying capacity and deciding training schedules, management strategies, and allocation of resources for reclamation. The methodology described is a sound way to describe correlations between biomass and effects at a specific time. This study does lack temporal resolution; therefore, decisions based on increases and decreases on growth rate cannot be made with confidence not having additional belowground biomass data. Changes in growth rate may be of greater concern, but logistics and funding constrained this study to one sampling per year.

CHAPTER 7: RECOMMENDATIONS FOR FUTURE WORK

The following are ideas for further work in quantifying military disturbance and land management effects on biomass and soil strength:

- Research in changes of growth rate based on treatment would be essential to understand growth dynamics. Increasing the temporal resolution of sampling to the window of interest, i.e. week, month, would give growth rates before and after treatments. Developing more accurate biomass models would allow better ideas of water use and soil moisture.
- More years of treatments and collections should be done in order to understand true impacts of disturbance as they are related to yearly changes in climate, varying impact application dates, recovery of vegetation, or long term changes in plant communities. Determining exactly how belowground biomass and soil strength parameters react to these changes would be very beneficial to land managers.
- If soil strength changes, based on belowground biomass changes, is of most concern then more direct measurements of physical parameters linked to the theory of soil strength should be taken, i.e. cohesion and direct shear strength.
- In order for more extensive belowground biomass research to take place, new methodology in sample collection and processing will need to be developed. The cost and time associated with producing final results must be lowered to increase the number of replications.

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APPENDIX A: BOX PLOT DIAGRAMS OF CONTINUOUS PARAMETERS BY TREATMENTS

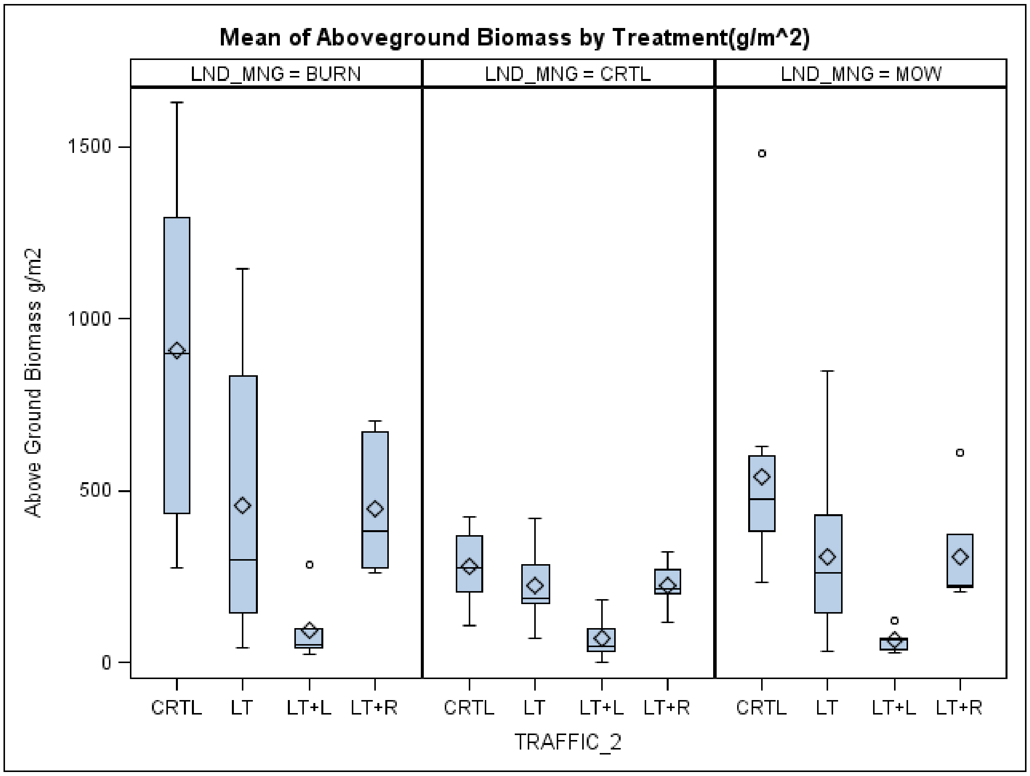

Figure A.1: Effect of treatment interaction on aboveground biomass

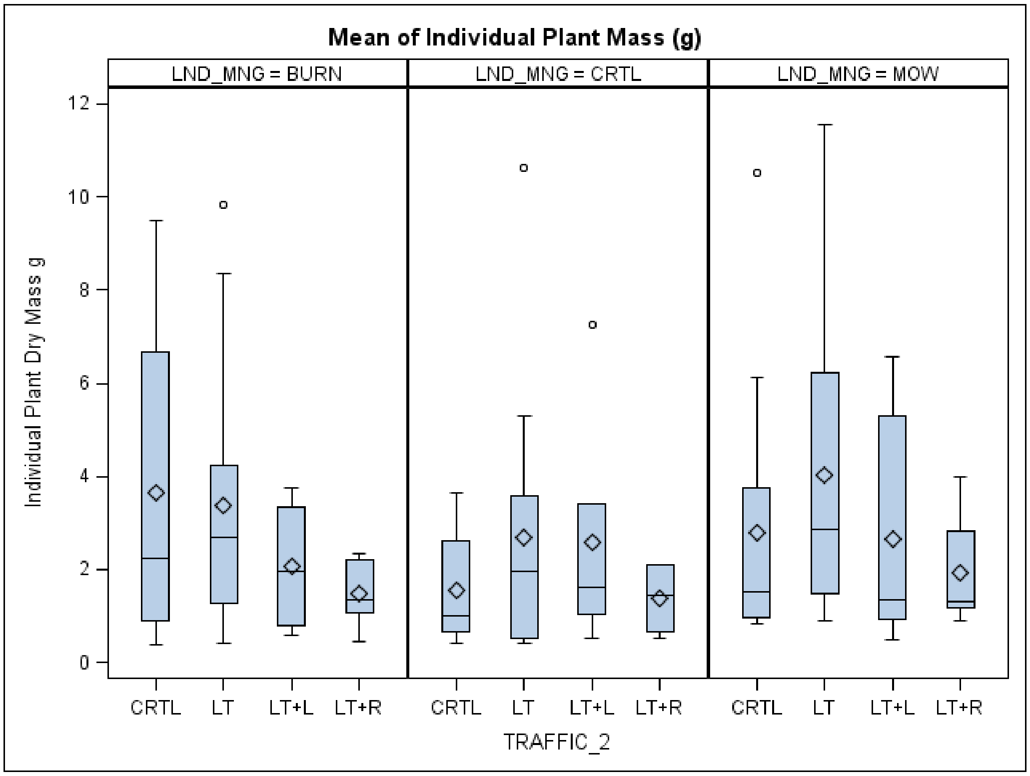

Figure A.2: Effect of treatment interaction on individual plant dry weight

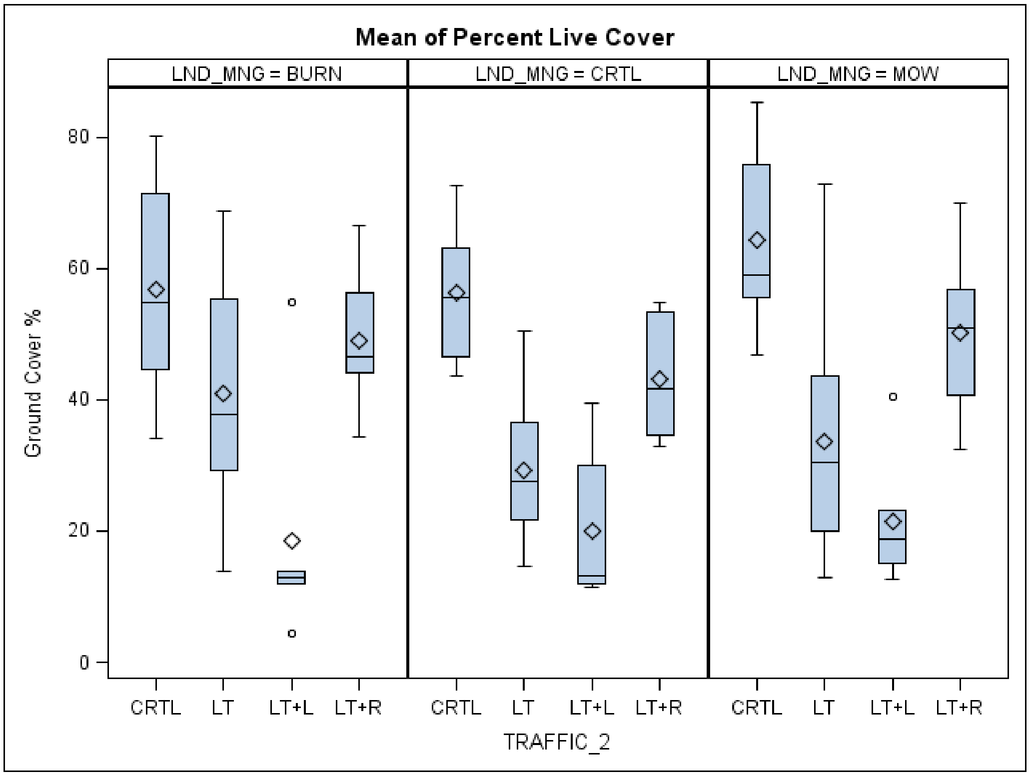

Figure A.3: Effect of treatment interaction on percent live ground cover

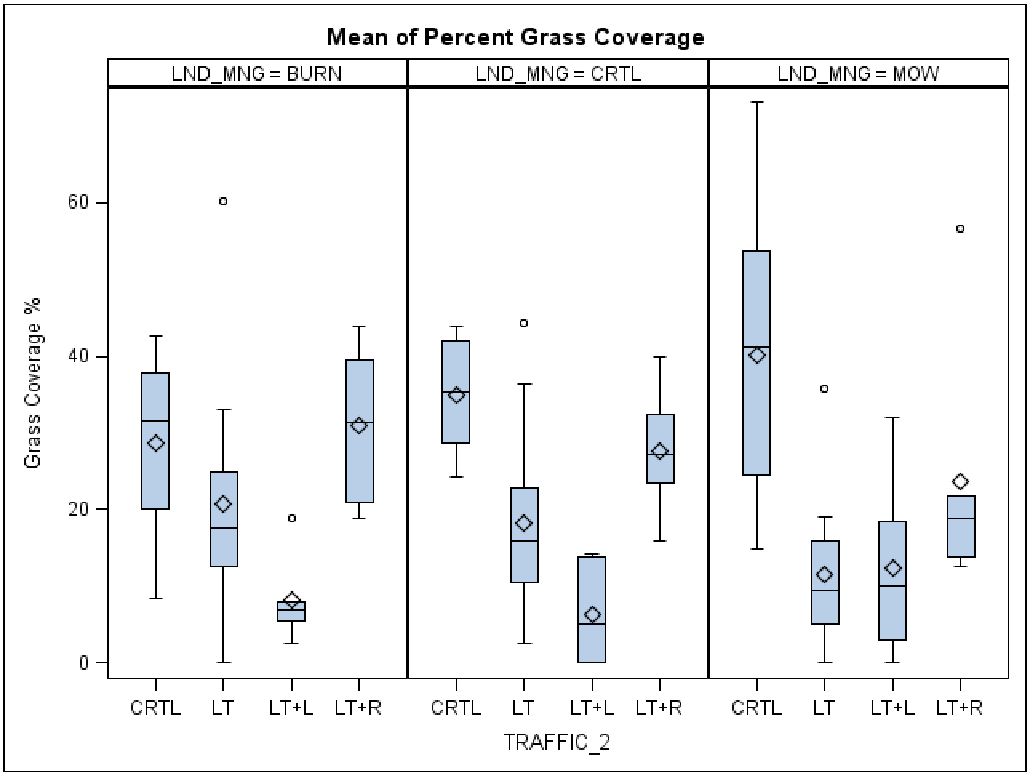

Figure A.4: Effect of treatment interaction on percent live grass cover

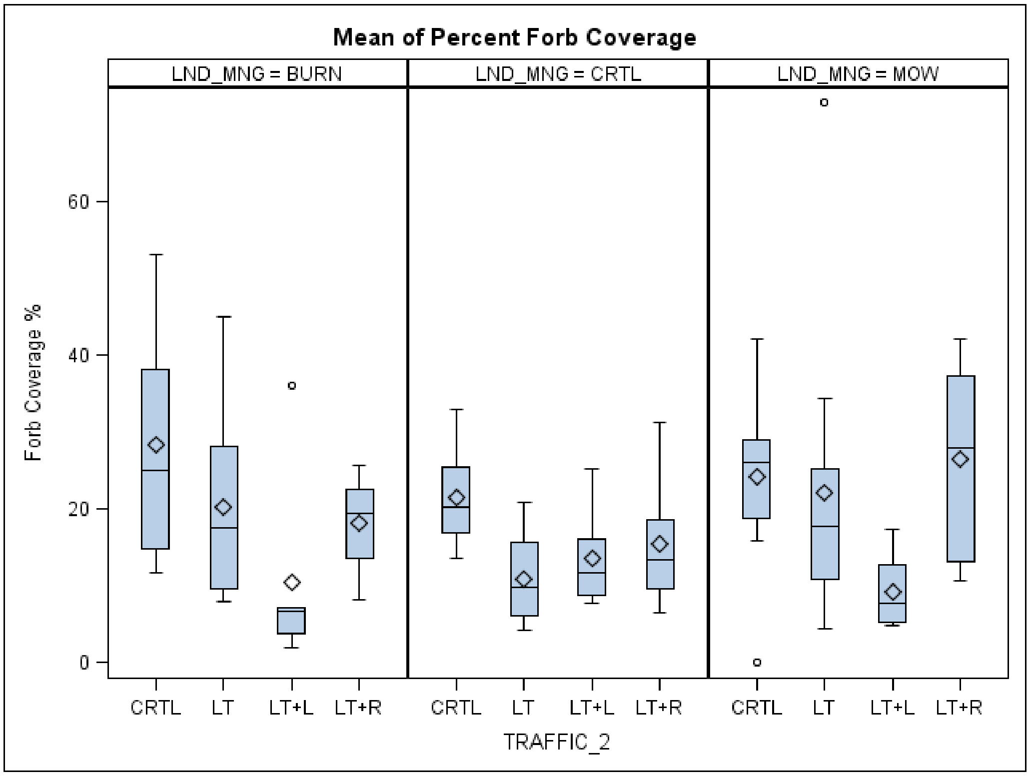

Figure A.5: Effect of treatment interaction on percent live forb cover

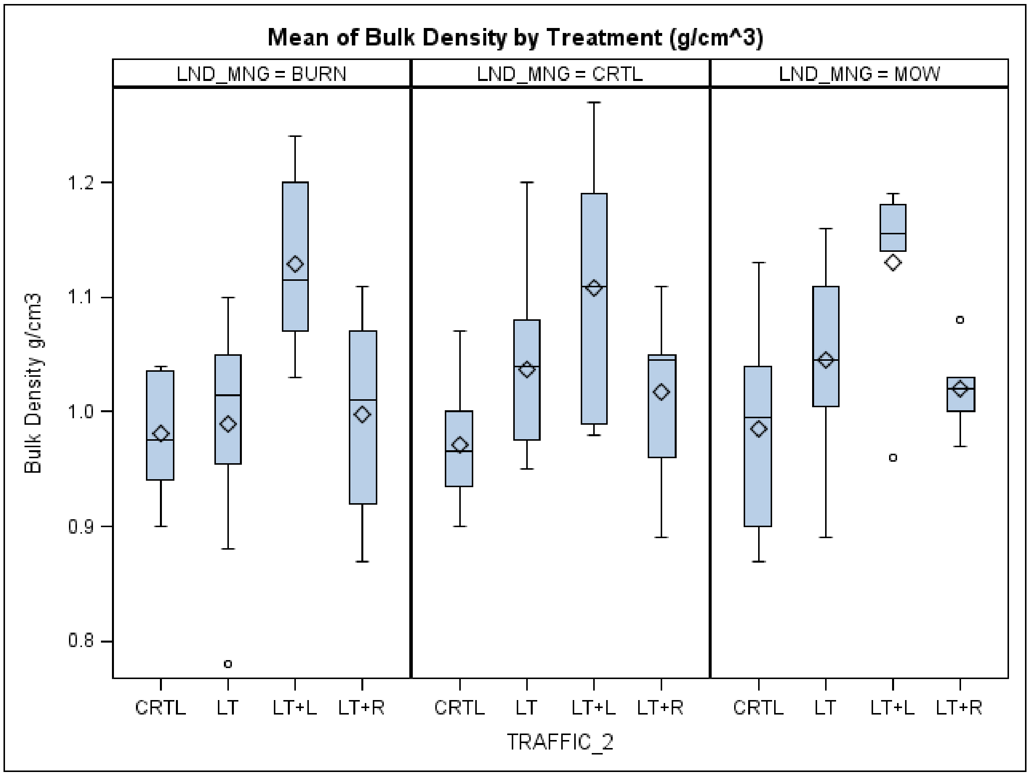

Figure A.6: Effect of treatment interaction on bulk density

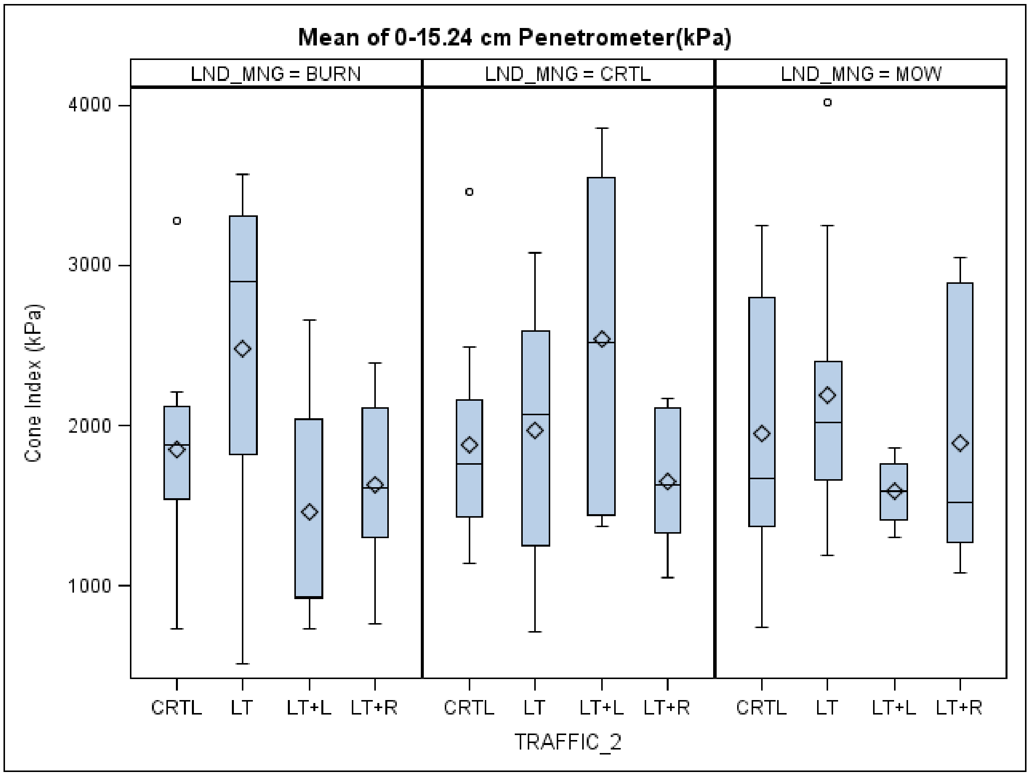

Figure A.7: Effect of treatment interaction on cone index (0-15.24 cm)

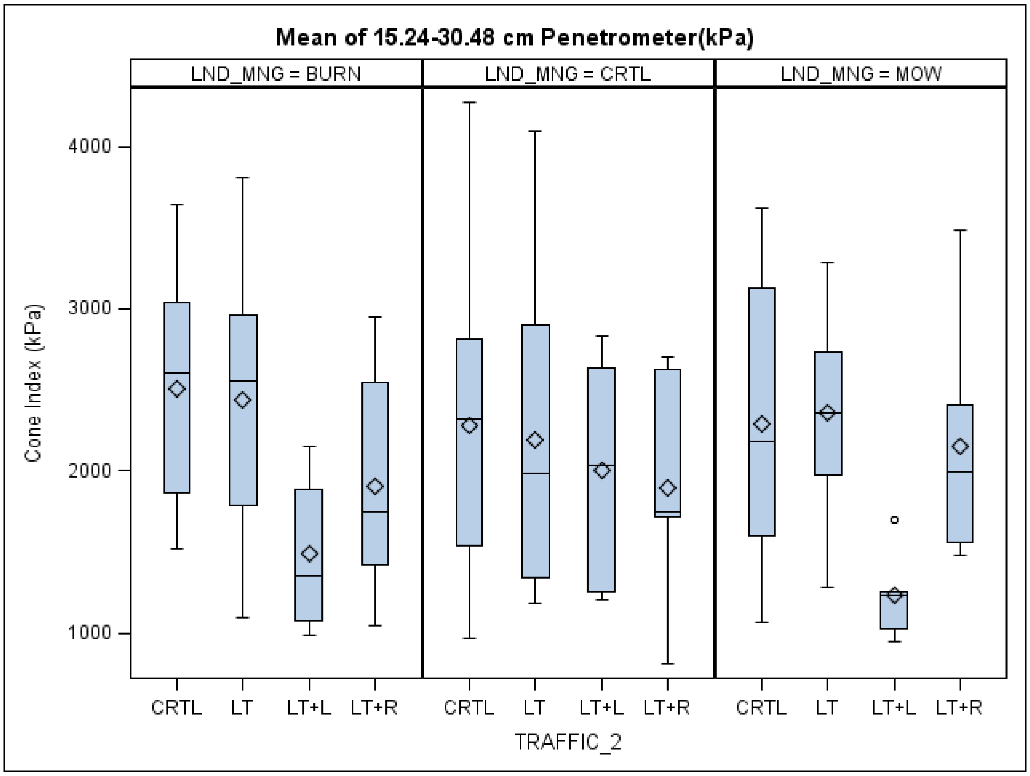

Figure A.8: Effect of treatment interaction on cone index (15.24-30.48 cm)

APPENDIX B: EXAMPLE SAS CODE

```
proc import datafile="C:\Users…\Riley Data\RLY_2010_2011_2012.csv"
     out=ROOTS
     dbms=csv
     replace;
       DATAROW=2;
run;

data CRTLOUT;
set ROOTS;
label ROOT_g_m2 = 'Below Ground Biomass g/m2';
label Bulk_Density_gpercm3 ='Bulk Density g/cm3';
label Trt = 'Treatment';
label Veg_mass_gperm2 = 'Above Ground Biomass g/m2';
label PLT_Mass_g = 'Individual Plant Dry Mass g';
label TDR_Moisture = 'TDR Moisture Content (%)';
label PLT_TYP = 'Plant Type';
label Location = 'Block';
label PEN_0_6 = 'Cone Index (kPa) Top 15.24 cm';
label PEN_6_12 = 'Cone Index (kPa) 15.24 cm to 30.48 cm';
label PER_Cover = 'Live Ground Cover %';
label PER_Grass = 'Grass Coverage %';
label PER_Forbs = 'Forb Coverage %';

if Year = 2010 then delete;
if Location = 'BB5' then delete; *BB5 and EE1 were control blocks;
if Location = 'EE1' then delete;
if TRAFFIC = 'LT' AND Track = "OUT" then delete; *OUT of track measurements
could not be included as control;
if TRAFFIC = 'HVY' AND Track = "OUT" then delete;
run;

*Example of Box Plot Code;
title 'Mean of Belowground Biomass by Land Management Practice(g/m^2)';
ods graphics on;
proc sgpanel data=CRTLOUT;
panelby LND_MNG/columns=3;
vbox ROOT_g_m2;
ods graphics;
run;

title 'Mean of Belowground Biomass by Traffic Level(g/m^2)';
ods graphics on;
proc sgpanel data=CRTLOUT;
panelby TRAFFIC_2/columns=4;
vbox ROOT_g_m2 ;
ods graphics;
run;

title 'Mean of Belowground Biomass by Treatment(g/m^2)';
ods graphics on;
proc sgpanel data=CRTLOUT;
panelby LND_MNG/columns=3;
vbox ROOT_g_m2/ category=TRAFFIC_2;
ods graphics;
```

```
run;

*Example of Means Calculation;
data CRTLOUT_TRAFFIC;
set CRTLOUT;
run;

proc sort data=CRTLOUT_TRAFFIC;
by TRAFFIC_2;
run;

proc means data=CRTLOUT_TRAFFIC;
var Bulk_Density_gpercm3;
by TRAFFIC_2;
run;

*Example AICc Calculation with Fixed Effects and Interaction (one statement
for each model);
ods html;
ods graphics on;
proc mixed data=CRTLOUT plots=all;
      class TRAFFIC_2 LND_MNG;
      model ROOT_g_m2 = TRAFFIC_2 LND_MNG TRAFFIC_2*LND_MNG;
run;
ods html close;
ods graphics off;
```

APPENDIX C: ACRONYMS

Table C.1: Acronym Components

Acronym	Initial Components
AIC	Akaike information criterion
AICc	Corrected Akaike information criterion
ANPP	annual net primary production
AOI	area of interest
ARV	army recovery vehicle
ASTM	American Society for Testing and Materials
CBR	California bearing ratio
CEC	cation exchange capacity
CERL	Construction Engineering Research Laboratory
CI	cone index
CIV	Clegg impact value
CRREL	Cold Regions Research and Engineering Laboratory
ERDC	Engineering Research and Development Center
GDD	growing degree day
GSL	Geotechnical and Structures Laboratory
ITAM	Integrated Training Area management
KSU	Kansas State University
LAI	leaf area index
LCTA	Land Condition-Trend Analysis
MBC	microbial carbon

MBT	main battle tank
OM	organic matter
OPAL	Optimal Allocation of Training Lands
PVC	poly-vinyl chloride
SRP	Sustainable Range Program
TDR	time domain reflectometry
UIUC	University of Illinois Urbana-Champaign
WES	Waterways Experimental Station