Juniper Effects on Grassland Soil Nutrient Availability

by

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ABSTRACT

The February 2008 study of a Snowflake, Arizona site measured changes in soil organic carbon, total nitrogen, extractable phosphorus, and soil moisture, to determine what affect One-seed Juniper (*Juniperus monosperma*) trees have on surrounding soil, thus affecting native grass growth. Increasing juniper densities in grasslands also decrease populations of some grassland bird species. Measurements were taken each meter along a twelve meter line transect, moving from juniper trees, through a bare soil area and into a grassland. Non-linear relationships were examined, in regard to distance from the tree and juniper root mass. Relationships were examined to determine any affect of the juniper tree on soil characteristics along the transect. Organic carbon decreased as distance increased from the trees (F=4.25, df=46, p=0.020). Soil moisture increased with distance from the trees (F=5.42, df=46, p=0.008), and juniper root mass, of roots less than 1 mm diameter, significantly decreased with distance away from the trees (F=11.29, df=46, p=0.0001). Total nitrogen and extractable phosphorus did not significantly change with distance from the tree, or presence of juniper roots. This data is important as grassland restoration projects rely on the availability of soil nutrients and water for reestablishment of native grass species.

DEDICATION

This thesis is dedicated to my lovely wife Carol, and my family. Their continuous encouragement and support gave me the strength and focus to complete this thesis and program. I thank you as the Earth thanks the Sun…

ACKNOWLEDGMENTS

Special thanks to Jim Horsley and Leslie Hasty for the generous use of their property for this study.

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INTRODUCTION

The increasing density and distribution of one-seeded juniper (*Juniperous monosperma*) has been changing the landscape of the American West for the past 130 years (Rau et al., 2007; Briggs et al., 2007). Short grass steppe communities have gradually converted to juniper woodlands (Miller and Wigand, 1994; Waichler et al., 2001). The loss of grasslands, and the impact this has on agriculture, farming and ecological biodiversity has led to numerous studies on these expanding juniper woodlands.

Once confined to fire limited areas, junipers now occupy almost 24 million hectares of the Western United States (Pierson et al., 2007; West, 1984). This increase in juniper trees can have an impact on soil nutrient levels and availability (Klemmedson and Tiedemann, 2000; Pierson et al., 2007), limiting both nutrients and water for surrounding vegetation. This impact becomes more pronounced with increased juniper density, as each tree's 'island of fertility' changes the distribution of the nutrients in these former grasslands (Tiedemann and Klemmedson, 1995).

As efforts continue to restore juniper invaded areas back into grasslands, it is important to continue to learn as much as possible about the relationship between juniper and grasses. Although the successional patterns and responses of juniper have been well documented (Bates et al., 2007(a); Breshears et al., 1997; Klopatek, 1987), knowledge of other processes, specifically nutrient distribution and cycling in these environments, is still lacking (Bates et al., 2007(a)). Most previous studies have compared soils directly under trees to interspace soils only. Later studies have examined possible tree root influences on soil properties up to a distance of 2 m away from the tree (Amiotti et al., 2000). However when the study site in Snowflake, Arizona, is considered, it appears that juniper trees may have an influence on surrounding soils potentially up to 10 m away from the edge of their canopy. The trees at this site have bare patches of soil extending out to five meters past the canopy. Past this distance, grasses gradually increase in density. This study examines the effect that established juniper trees have on grassland soils up to 10 m in distance from the tree. This study looks at nutrient distribution along a gradient, moving away from juniper trees and into the grassland. This belowground data can thereby provide information which is often lacking in grassland restoration projects.

LITERATURE REVIEW

For the past 130 years, the One-Seeded Juniper (*Juniperus monosperma*) has increased in density and distribution across the American West, to include the state of Arizona (Miller and Wigand, 1994). The current estimates of 19-25 million ha represents an almost 5-fold increase in historic juniper woodlands (Davenport et al., 1996), indicating that almost 97% of current juniper woodlands have become established after 1880 (Miller, 1995). Historically, these woodlands were only prevalent in fuel limited and fire restrictive areas (Johnson and Miller, 2006). Although climate change (specifically precipitation and temperature) has been attributed to some of this increase (Miller and Wigand, 1994), most of this increase is attributed to anthropogenic factors.

The factors with the greatest influence on increased juniper distribution are decreased natural fire regime and livestock grazing. A decrease in natural fires has increased juniper populations due to lack of a natural control mechanism which historically limited expansion (Baker and Shinneman, 2004; Van Auken, 2000). Prior to 1871, before settlement of the west, the natural fire regime in juniper-sagebrush communities was a fire every 12 to 15 years (Miller and Rose, 1999). The largest expansion of juniper trees throughout the West occurred from 1885 to 1925. From this time until the present, the natural fire return interval has decreased to approximately every 100 years (Miller, 1995; Miller and Rose, 1999). Natural fires through grasslands and steppe communities effectively limit expansion of juniper trees as junipers less than 40 years old are easily killed by fires (Miller and Wigand, 1994). Natural fires have been limited primarily by decreased fine fuel accumulation, as a result of increased livestock grazing (Baker and Shinneman, 2004; Miller and Rose, 1999; Miller and Wigand, 1994). The grasses and forbes which normally accumulate to provide fine fuels for natural fires, are mostly consumed by livestock herds. With less fuel available, fires are not able to spread through grasslands, thus limiting their effect on juniper expansion. With low palatability and protein content, livestock avoid eating juniper sprouts (Dittberner and Olsen, 1983). The exception to this fire limiting influence is alligator juniper (*Juniperus deppeana*), which has several adaptations which make it resistant to fire including scaly, tough outer bark, and a canopy higher than other juniper species. This adaptation is a result of the ecosystems in which alligator juniper occur. They are more frequent in forests and mountain regions where as *J. monosperma* are more prevalent in grasslands and arid environments (US Forest Service Fire Effects Information System, 2002).

The ecology of juniper trees presents an adaptive, well established species. The one-seeded juniper can be found throughout the western United States in desert grasslands and woodlands (US Forest Service Fire Effects Information System, 2002). They are generally long lived (can grow over 200 years) and at maturity stand between 3-12 m in height. Most junipers produce seeds every two to five years, with maximum seed production occurring after 50 years of age (US Forest Service Fire Effects Information System, 2002). The tree produces both a tap root and lateral root system. The lateral roots are generally found within the first 20 cm of surface soil, while the tap root can extend down into the soil up to 60 meters (Foxx and Tierney, 1987). The one-seeded Juniper can also arrest active growth when water availability is low, and resume growth when water becomes more available (US Forest Service Fire Effects Information System, 2002). This adaptation, combined with a well developed root system, enables the juniper to colonize in harsh, arid climates.

The result of increased juniper density is a decrease in herbaceous and grass species, resulting in large bare patches of soil in the inner spaces between juniper trees (Miller et al., 2000). Bare patches of soil can have many negative effects on the surrounding ecosystem, to include increased runoff (Bates et al., 2007(b); Landis and Bailey, 2005; Pierson et al., 2007; Van Auken, 2000), increased soil erosion (Landis and Bailey, 2005; Pierson et al., 2007; Van Auken, 2000), loss of herbaceous and forage species diversity (Landis and Bailey, 2005), and an increase in invasive species (Bates et al., 2007(b)). Changes in juniper density also have an effect on wildlife species composition within the ecosystem. An example of this affect is ground nesting birds, which decrease in abundance as juniper density increases (Rosenstock and VanRiper, 2001). Due to these effects on grassland ecosystems, there has been increasing attention paid to grassland restoration, and reducing the spread of juniper trees into grasslands. The primary belief is that junipers invaded areas which were historically grasslands, and these grasslands can be restored by eradication of the junipers.

The purpose of restoration is to prevent irreversible changes to ecosystems. If ecological thresholds are crossed, it is possible this would lead to trajectories outside the ecosystems normal range of variability (Society for Ecological Restoration, 2002). Land managers try to minimize the spread of junipers in hope that the presence of juniper will not irreversibly alter the ecosystem, so grass can once again flourish. Because of the potential economic value of grasslands, from both recreation and agriculture, land owners and managers are under increasing pressure to control the expansion of juniper trees into grasslands (Belsky, 1996). In general, the cycle of an invading vegetative species into an ecosystem can have a continuing negative effect on the invaded area. The presence of invasive species, combined with changes in soil characteristics, can lead to desertification. This creates positive feedback for further invasion (Schlesinger and Pilmanis, 1998). Although desertification does not occur with all vegetative species, junipers have been shown to cause this condition in grasslands (Tiedemann and Klemmedson, 1995).

Since the 1960's, the primary methods of juniper control has been prescribed fire, mechanical cutting and/or removal of the entire tree from the landscape (Bates et al., 2007). These are generally the same practices as for control of any woody invasive vegetative species. Though they can be successful at removing the invasive species quickly, these methods are not without negative effects. Complete tree removal results in loss of nutrient capitol from the site. This nutrient loss can affect future site growth and development (Schlesinger et al., 1996). A decrease in available nutrients can also effect native vegetation, causing it to grow less vigorously, which can result in increased invasive species.

Burning felled juniper trees can have negative effects on the surrounding environment. Burning trees can volatize nutrients, specifically sulfur and nitrogen, increasing nutrient loss to the system (Klemmedson, 1976). The above examples suggest the complex relationships which exist within grassland/juniper communities. They also demonstrate that before large sums of money are allocated to restoration projects, baseline data concerning these relationships should be collected and analyzed; otherwise negative results may arise from unintended consequences (Belsky, 1996; Tiedmann and Klemmedson, 2000).

The effect of many species on surrounding soils has been well studied and termed the 'tree island effect' (Amiotti et al., 2000; Zinke, 1962). In general, the tree island effect demonstrates how trees mine nearby soils for water and available nutrients. Large established trees with well developed lateral root growth are able to extract nutrients from farther distances, and decrease plant-available nutrients in large areas. This has been demonstrated where nutrients have become available to less competitive herbaceous species, when more competitive tree species have been removed from invaded sites (West, 1984). When the leaves and other tree litter fall to the ground, this accumulation of resources creates an 'island of fertility' or resource island, under the tree (Roberts and Jones, 2000). These nutrient resources can then be recycled back into the tree for biomass or leaf production (Tiedmann and Klemmedson, 2000). This island, although rich in nutrients, represents nutrient removal from the surrounding area (Bates et al., 2007; Roberts and Jones, 2000; Van Auken, 2000; Zinke, 1962). In some cases this nutrient mining can be so extensive as to reduce growth of other plant species (Roberts and Jones, 2000; Schlesinger et al., 1996). This phenomenon has been demonstrated in many vegetation species. An example is creosote bush (*Larrea tridentata*), which has gradually replaced local grasses since the early 1900's in Northern Chihuahuan Desert grasslands. Nitrogen levels are significantly higher under these shrubs than in the invaded grassland (Schlesinger et al., 1996).

Juniper invaded grasslands have also demonstrated the tree island effect, as more carbon has been found beneath juniper canopies as opposed to nearby grass canopies, and the grass islands had more carbon than the bare interspaces around them (Harrington and Williams, 2008). This carbon accumulates as a result of leafy and woody debris which fall from the trees and grasses. Carbon and plant available nitrogen have also been observed in greater quantity beneath mature trees, as opposed to younger trees of the same species in the same area (Tiedemann and Klemmedson, 2000).

The affect of the tree island can be increased by the tree canopy. It shields the ground from raindrop impact, leading to decreased runoff and erosion from under the tree (Schlesinger et al., 1996). The fertility island beneath the tree is also increased when rain flows down the trunk of the tree and deposits trapped dust and soil to the ground. Dust and soil which collect on the trunk and leaves as a result of wind deposition, represents nutrients which have been transported from interspace areas to beneath the tree (Zinke, 1962). Ultimately the exact cause of tree islands is not clearly known (Roberts and Jones, 2000). Wind and water redistribution of surface soils (Schlesinger, 1996), nutrient cycling, decomposition and litter fall (West, 1984) all play a role in the development of these islands.

Two of the most important plant nutrients required for plant growth, development and reproduction are nitrogen and phosphorus. These nutrients are generally found in low concentrations within soils (Brady and Weil, 1996). Nitrogen is especially limited in arid environments (Burke, 1989). These nutrients are considered macro nutrients, meaning that more than 0.1% of dry plant tissue is made up of these nutrients (Brady and Weil, 1996). Subsequently, nitrogen and phosphorus become less available in the soil as a result of competition. Nitrogen (plant available nitrogen in the form of ammonium, NH_4^+ and nitrate, NO_3^-) is essential to plant vigor as it enables plants to use carbohydrates for energy and building proteins (Brady and Weil, 1996). Phosphorus (plant available phosphorus in the form of $H_2PO_4^-$ and HPO_4^{2-}) is used by all plants for the production of ATP and NADPH. With these molecules plants are able to respire, conduct photosynthesis and transfer and store energy (Brady and Weil, 1996).

The role of carbon in plant growth and development is more indirect than nitrogen or phosphorus, however no less important. Carbon, which represents the largest component of humus and soil organic matter, serves as a primary food substrate for soil flora and fauna (Bradley and Weil, 1996). Many of these organisms are responsible for mineralization of phosphorus, sulfur and nitrogen. These nutrients are continuously cycled through the soil profile. Through decomposition, soil flora and fauna continues to cycle nutrients from organic forms to inorganic, plant available forms. This cycling makes it possible for plants to access and use these nutrients for growth and development. Without carbon as a substrate for soil flora and fauna, nutrients would remain in organic forms inaccessible to plants (Briones et al, 2009). Humus also increases soil aggregate stability. A well developed and stable soil structure can promote movement of air and water more efficiently and is less prone to wind and water erosion.

As part of the soil flora and fauna, mycorrhizae play an integral role in the ability of juniper trees to access critical nutrients, especially phosphorus (Pregitzer et al., 2002). Mycorrhizae form a mutualistic relationship with some plants, including juniper, where the plant provides an energy source for the mycorrhizae in the form of carbohydrate, and the mycorrhizae provide the plant with soil nutrients. The mycorrhizae produce acids which convert the organic forms of phosphorus to inorganic forms, and transport the phosphorus back to the plant. Mycorrhizae also increase the absorptive capacity of the roots by forming and living on the roots, which increases root surface area (Brady and Weil, 1996).

The distribution of nutrients in grasslands is in part a reflection of the ability of the grass roots to access and utilize these nutrients. Invading vegetation becomes a direct competitor for these nutrients. Generally the species with a more extensive and efficient root system can more effectively compete for available nutrients (Schlesinger and Pilmanis, 1998). Nutrient availability in soils can also be affected by roots of invading vegetation (Madsen et al., 2008). Although the influence of root systems on soils applies generally to all vegetation, the level and extent of influence is different for each species (Hartle et al., 2006). Thus, in order to determine the specific influence of a particular species, it needs to be studied specifically.

Juniper trees have been found to be good competitors for soil nutrients (Breshears et al., 1997; Krämer et al., 1996; Roberts and Jones, 2000). Even in harsh, arid environments, juniper trees ability to gain moisture and nutrients from shallow soils exacerbates the tree island effect (Landis and Bailey, 2005). A possible explanation for this high degree of adaptation may be related to juvenile root development in juniper trees. Juniper trees allocate high levels of structural carbohydrates to root development in juvenile trees (Krämer et al., 1996). As the tree ages, root development shifts from tap root development to fine lateral roots. This development of a fine lateral root system in the upper layers (25 cm) of soil maximizes nutrient uptake capacity (Miller, 1995). This lateral root system has demonstrated an ability to rapidly relocate phosphorus from interspace areas to the canopy of the developing juniper tree (Tiedeman and Klemmedson, 1995).

Juniper trees also have an effect on soil moisture levels of surrounding soils. Major soil hydrologic properties, such as soil sorptivity, unsaturated hydraulic conductivity and soil water content were all significantly affected by the presence of juniper trees (Madsen et al., 2008). Sorptivity (the ability of soil to absorb moisture by capillarity) is significantly increased in the presence of juniper roots, however unsaturated hydraulic conductivity (which is generally more influenced by soil texture), is lowest beneath juniper canopies. This demonstrates how the juniper trees decrease soil water availability beneath their canopies (Madsen et al., 2008). Soil water content increased with distance away from the tree (Madsen et al, 2008). The extent of influence the tree had on these properties was demonstrated up to a distance of eight times the radius of the canopy.

STUDY SITE

The study site is located 5 km south of Snowflake, Arizona, and approximately 270 kilometers North East of Phoenix (Figure 1). The property is at an elevation of 1740 m. The property was grazed as a cattle ranch until the 1980's (Debnar, 2007). Currently the land is privately owned and not used for grazing or agriculture.

The Western Regional Climate Center weather station 028012 is located 5 km from the study area. This station provides weather data from 1897 through August, 2009. For this period of record, the average winter low was -7° C, with an annual summer high of 23° C. Mean annual precipitation was 30.9cm, with an annual mean snowfall of 44.7 cm (WRCC, 2009). For this study the soil samples were taken on the 7th of February, 2009, when the average high temperature was 12.3° C and the average low was -5.8° C. Average high precipitation for study period was 1.1 cm and the average low was 0 cm (Figure 2 and 3). Although soil temperature was not measured for this study, a past study at this site reported average February soil temperatures between 3.8° C and 5° C (Debnar, 2007).

The site is grassland with varying degrees of juniper density (Appendix A). Other than juniper, dominant vegetation species include blue gramma (*Bouteloua gracilis*), Tobosagrass (*Hiliria mutica*), sand dropseed (*Sporobolus cryptandrus*) and fourwing saltbush (*Atriplex canescens*). Percent of grass cover variation defines this site, as density changes with distance from the trees, thus creating a 4 m bare section (from meter 2 to meter 6) constituting this study (Figure 4).

The site is at the intersection of two different soil series; Ketch and Barx. Textural analysis of soil and comparison with previous studies (Debnar, 2007), as well as NRCS data, indicate that the soil within this site is Barx. This soil is a fine-loamy, mixed, super active, mesic Ustic Calciargids, with a reported pH of 8.0 (USDA, 2005). Soil samples were taken between 10 and 20 cm, which is located within the AB horizon. This horizon is described as a sandy loam with moderate medium sub angular blocky structure, with a pH between 8.0 to 8.9 (USDA, 2005). All soil samples taken at this site were in the 8.0 to 8.9 pH range (Table 1). The AB horizon is described as having an average clay content of between 18 to 35% and a coarse fragment content of 1 to 15% (USDA, 2005). Soil samples taken at this site had an average clay content of 22.5% (Table 1) and coarse fragment content of 2.5%. A previous study at this site indicated average clay content ranging from 14% to 29%, and also found slight increases in clay content as distance from the trees increased (Debnar, 2007).

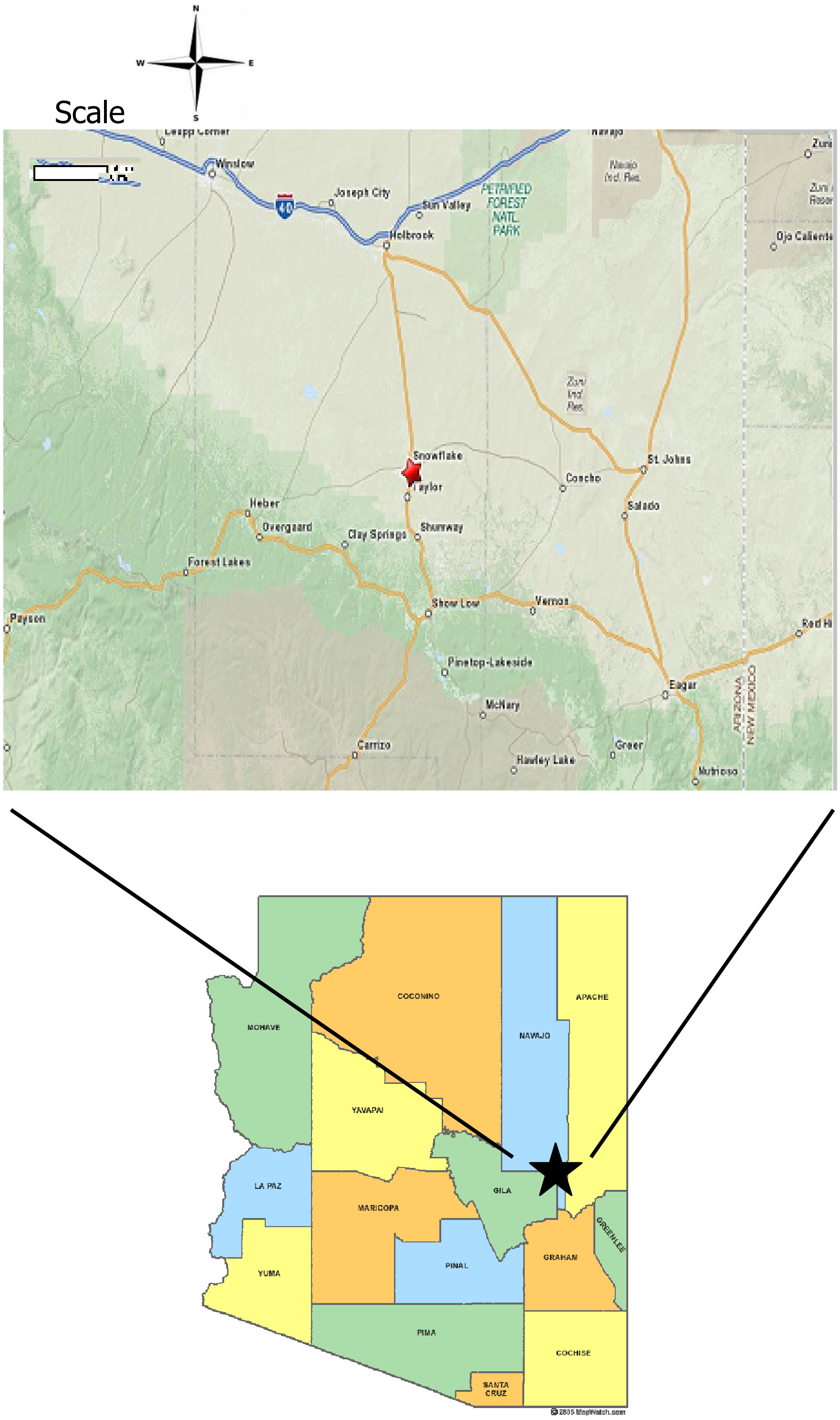

Figure 1. Location of Snowflake, Arizona, study site. (Map Quest, 2010; The University of Texas at Austin, 2010).

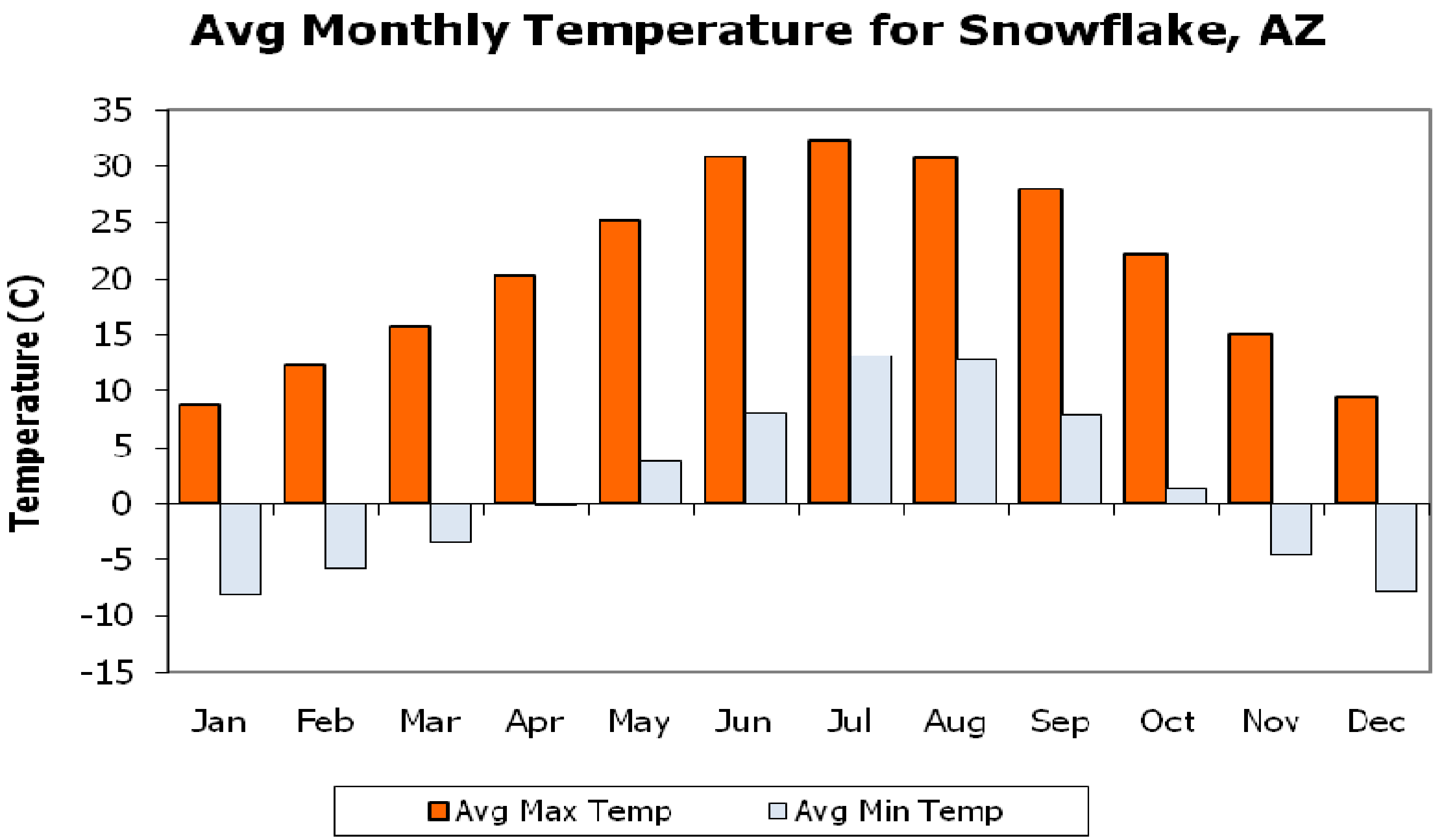

Figure 2. Average Monthly Temperature for Snowflake, Arizona, June 1897 to August 2009 (Weather Underground, 2010)

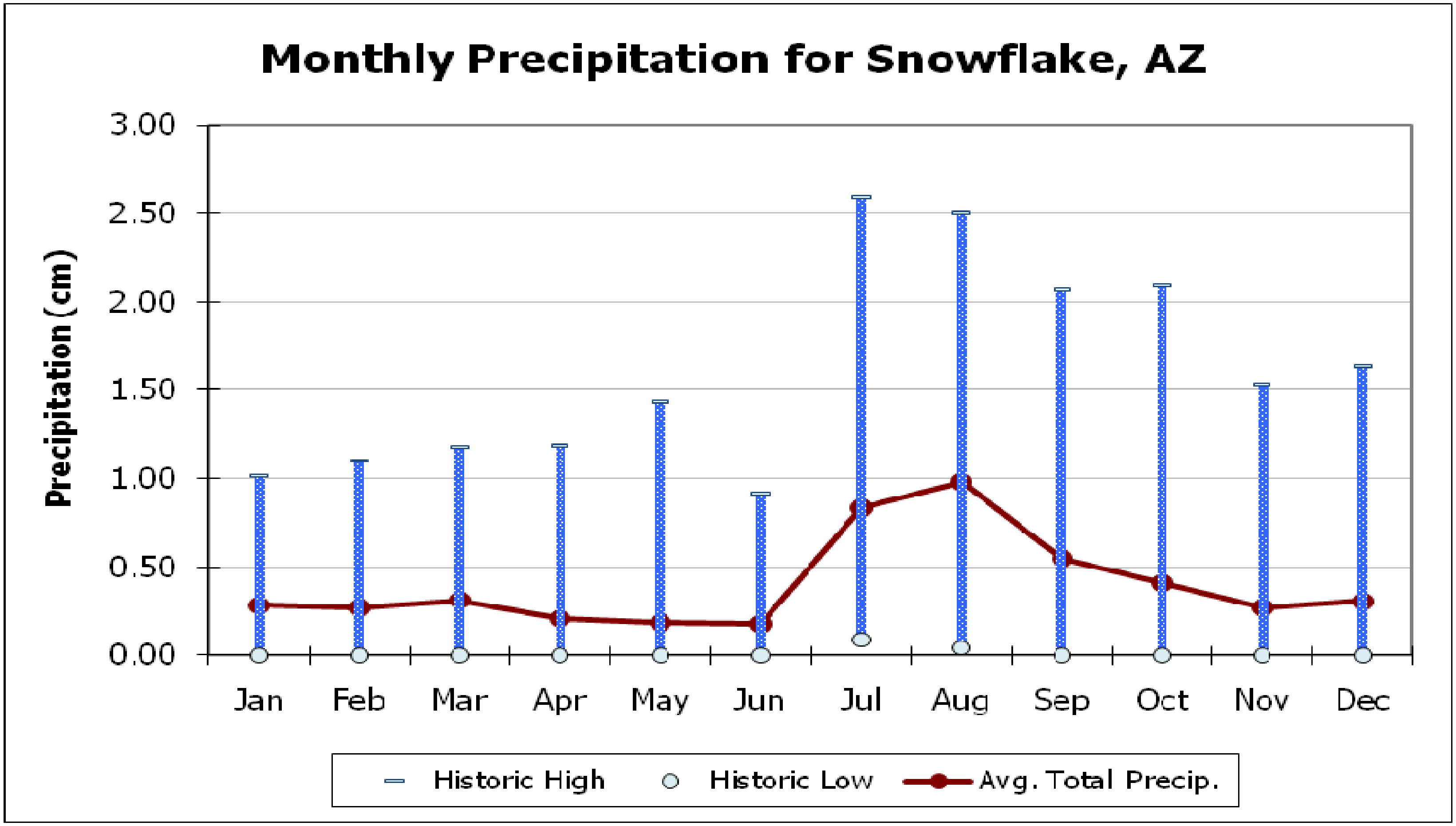

Figure 3. Monthly Precipitation for Snowflake, Arizona, June 1897 to August 2009 (Weather Underground, 2010)

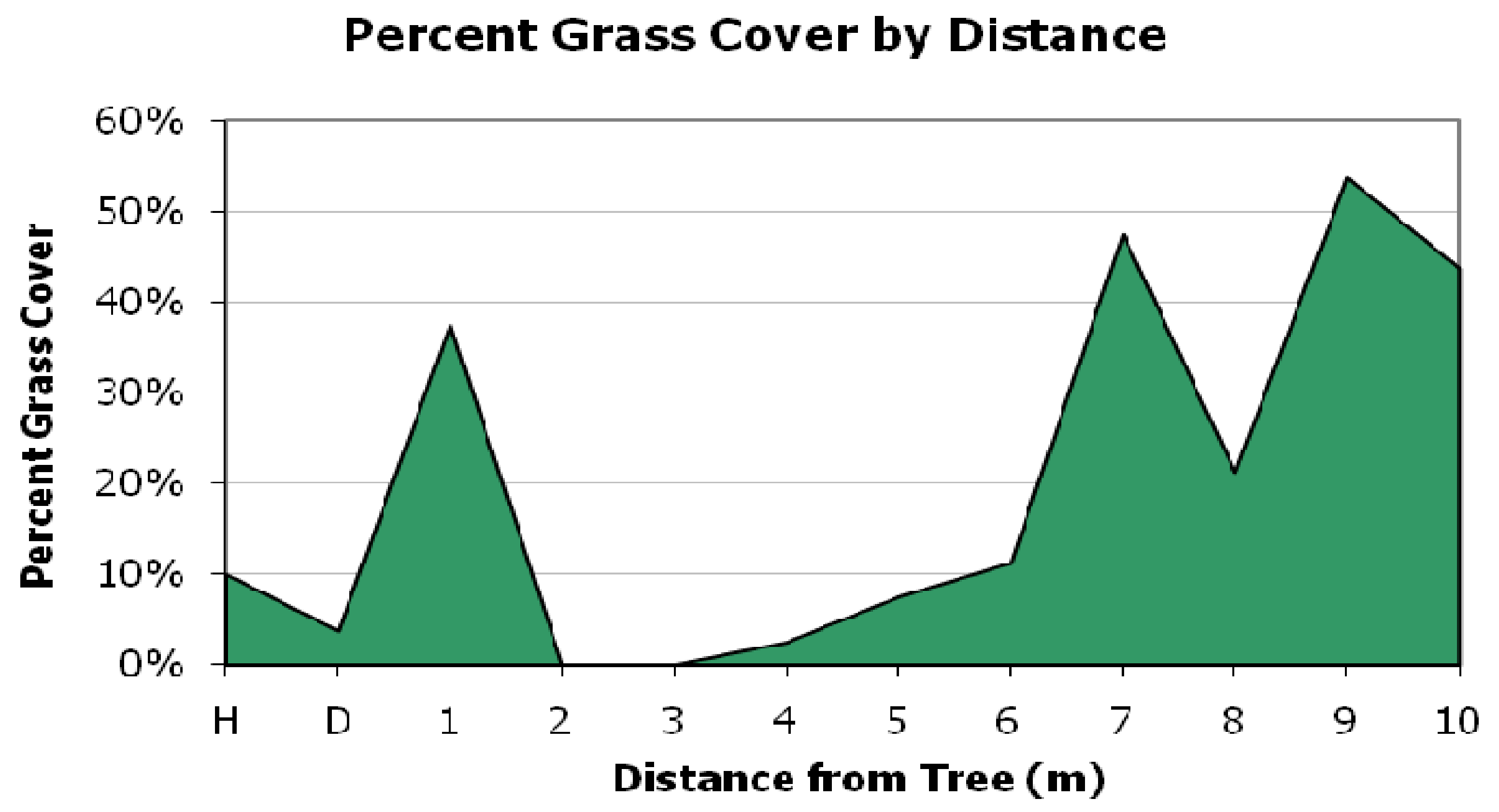

Figure 4. Grass cover by distance from tree, as a percent of total ground cover, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, AZ, February 7, 2009.

Table 1. Average clay percent and pH of soil samples, based on distance from tree, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, AZ, February, 2009.

Distance from Tree (m)	Clay (%)	pH
H	16.4	8.26
D	22.3	8.56
1	20.9	8.66
2	21.5	8.68
3	19.6	8.73
4	22.6	8.78
5	23.5	8.75
6	23.8	8.75
7	22.2	8.78
8	22.6	7.70
9	27.3	8.76
10	26.8	8.79
Mean	22.5	8.68
Std Error	0.838	0.04

METHODS

Field and Lab Procedures

The experimental plots were located within a 1 ha area of the study site, comprised of juniper trees, bare soil and grass. This area represents a border between invading juniper trees and juniper free grassland. For this study, four juniper trees were selected as a plot. Tree selection was based upon height, bole and location. Trees were between 3 to 4 m in height, stem diameter of 1 to 1.5 m at ground level, and had no other juniper growth between them and the open grassland. The four trees were spaced approximately 5 m apart and in a straight line from northeast to southwest. Soil samples were collected in February, 2009.

Moving from east to west, away from the juniper trees, a bare patch was present, which gradually increased in grass density over a 10 m distance. Grass density was measured through the study site with a Daubenmire 20 cm x 50 cm frame (Daubenmire, 1959). Results were recorded as percent grass cover.

At each tree, a westward line transect was measured from the base of the tree, moving away from the tree through the bare soil, into the grassland. A total of 12 soil samples were taken along this transect starting at half way between the base of the trunk and canopy, then at the drip line of the canopy (usually about 2 m from the trunk). The remaining 10 samples were taken at 1 m intervals from the drip line. Depending upon canopy size, the last sample was about 12 m from the base of the tree, resulting in 12 soil samples per transect, for a total of 48 samples. A hole was dug at each sample location and a 5-sided metal box (40 x 4 x 10 cm) was placed at 10 cm depth, centered on the flattened soil face, and hammered into the soil. This enabled collection of a soil/root sample from 10-20 cm of depth. Sample depth of 10 cm-20 cm was used because prior analysis indicated this depth to be the zone of maximum root density for both grasses and juniper. Each sample was separately bagged and marked. Soil samples were analyzed in triplicate for texture, moisture, pH, total nitrogen, extractable phosphorus, organic carbon and root mass.

Soil and Root Analysis

Soil texture was determined by hydrometer method of Bouyoucos (1962) with a settling time of 2 hours. Soil textural classes followed the USDA system (USDA, 2005). Coarse fragment percent was determined by weight of material retained in a 2 mm sieve. Soil pH was measured using an electrode in a 1:1 soil/water mixture (Thomas, 1996).

Soil moisture percent was determined by comparing soil wet weight to oven dry weight, after samples were dried in an oven at 110^{o} C for 24 hours.

Soil total nitrogen was measured using a PerkinElmer 2410 Series 2 Nitrogen Analyzer. This instrument determines nitrogen through combustion with oxygen, based on the chemistry of Dumas and Liebig (PerkinElmer, 2007). Results are expressed on a percent basis of the soil sample.

Soil extractable phosphorus was determined using sodium bicarbonate as the extracting agent (Olsen, 1954). This test measures extractable inorganic phosphorus. Spectrophotometer used was Thermo Scientific Genesys 20, model 4001/4.

Total organic carbon was measured by the Walkley-Black method (Walkley, 1947) using 1 g of crushed soil passed through a 0.5 mm sieve. This method measures the level of readily oxidizable organic carbon, not total carbon in the soil.

The relationship between tree height and root development necessitated trees of similar height for comparison in this study, as height can be a more accurate indicator of tree development and root parameters, than age alone (Krämer et al, 1996). It was important to have similar root development among sample trees to decrease variability in nutrient uptake. The parameters important to nutrient uptake include root length and biomass. Juniper roots less than 1 mm diameter were used for this study because they function primarily as nutrient uptake for the trees, whereas larger roots are mostly used by the tree for nutrient and water transport (Krämer et al., 1996). The roots were separated from the soil of each individual sample and oven dried at 100^{o} C for 24 hours. Roots were then classified as juniper or non-juniper (grass) roots. Diameter was measured with a standard caliper, with roots being classified as greater than 1 mm diameter or less than 1 mm. The roots were then weighed on a standard balance.

Statistical Analysis

There is one primary and one alternate hypothesis examined in this study. The primary hypothesis tested whether there was a relationship between available soil nutrients and distance from juniper trees. Distance and root mass were used as independent variables and carbon, nitrogen, phosphorus and soil moisture were dependent variables. The experimental design was random plot, with each tree as a replicate, and distance and juniper root mass as treatments. The statistical analysis was non-linear regression. The factors tested were distance from the tree and levels of available nutrients (total nitrogen, organic carbon and extractable phosphorus), and moisture in the soil.

Non-linear regression was performed in Excel and SPSS (version 16) Statistical software (IMB Corp., 2010). ANOVA was used to determine strength of relationship. Strength of relationship was considered significant at $p<0.05$. Data for soil moisture, total nitrogen and organic carbon were all square root transformed prior to analysis to eliminate skew caused by raw data being in percent form.

The alternate hypothesis tested weather there was a relationship between available soil nutrients and moisture, and juniper root mass. This hypothesis was also tested using non-linear regression.

Non-linear regression was performed in Excel and SPSS (version 16) Statistical software. ANOVA was used to determine strength of relationship. Strength of relationship was considered significant at $f<0.05$. Data for soil moisture, total nitrogen and organic carbon were square root transformed to eliminate skew induced by data being in percent form.

RESULTS

Juniper Root Mass

Juniper root mass was tested for significance by distance from the juniper tree. Juniper roots with a diameter of less than 1 mm were used for the test as these roots accomplish most of the nutrient uptake in juniper trees (Krämer et al., 1996), thus having the potential for greater influence on surrounding soil. Root mass ranged from zero grams to 0.62 grams of root material per sample (Table 2). Average root mass per sample was 0.25 grams

Non-linear regression indicated a significant quadratic relationship between root mass and distance (Figure 5). The resulting equation was $Y= 0.2325 + 0.0369D - 0.0041D^2$, where y = juniper root mass and D = distance from the tree.

Soil Moisture

Soil moisture was tested for significance with distance from the tree. Soil moisture ranges by sample were from 6.1% to 13.7%, with an average 10.3% soil moisture per sample (Table 2). Non-linear regression indicated a significant quadratic relationship between soil moisture and distance from the tree (Figure 6). The resulting equation was $Y = 0.2325$

- $0.0369D + 0.0041D^2$, where y = square root transformed soil moisture data and D = distance from the tree.

When soil moisture was tested with juniper root mass, non-linear regression indicated no significant relationship (Figure 7).

Soil Organic Carbon, Total Nitrogen and Extractable Phosphorus

Total organic carbon tested as a result of distance from the tree. Organic carbon ranged from 0.25% to 1.4%, with an average 0.52% organic carbon available per sample (Table 2). Non-linear regression indicated a significant quadratic relationship between organic carbon and distance from the tree (Figure 8). The resulting equation was $Y = 0.803156 - 0.1015D + 0.006975\,D^2$, where y = square root transformed organic carbon data, and D = distance from the tree. Non-linear regression analysis did not indicate a significant relationship between organic carbon and juniper root mass (Figure 9).

Total nitrogen was tested for significance by distance from the tree. Total soil nitrogen content ranged from 0.017% to 0.080%, with an average of 0.043% (Table 2). Non-linear regression analysis indicated no significant relationship (Figure 10). When total nitrogen was tested with root mass there was no significant non-linear regression relationship (Figure 11).

Extractable phosphorus was tested by distance from the tree. Phosphorus ranges were from 0.008 mg/kg to 0.149 mg/kg, with an average of 0.063 mg/kg (Table 2). Non-linear regression results show no significant relationship between distance from the tree and extractable phosphorus in the surrounding soil (Figure 12). When extractable phosphorus was tested with root mass, non-linear regression indicated no significant relationship (Figure 13).

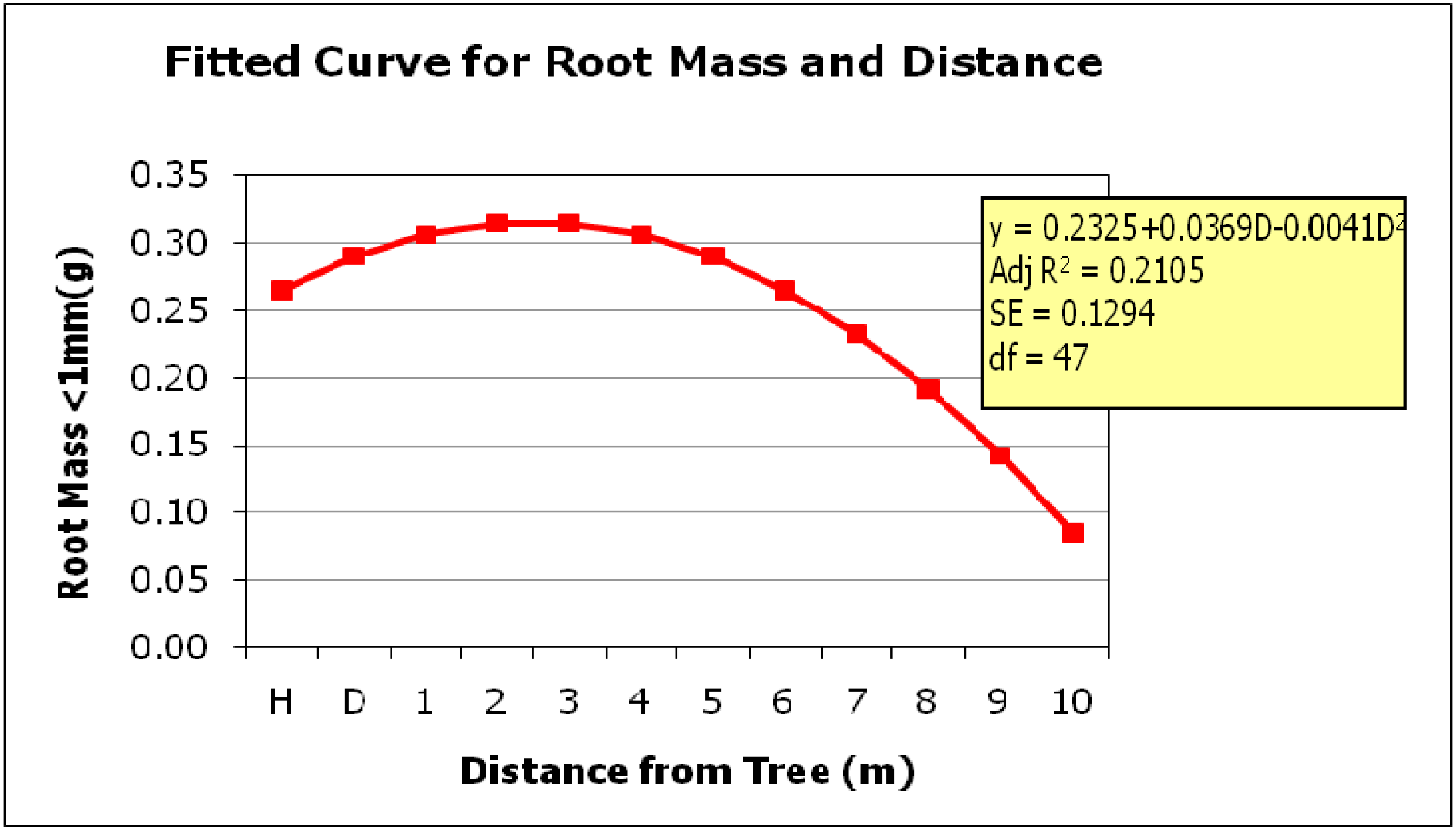

Figure 5. Fitted curve for non-linear regression of juniper root mass and distance, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

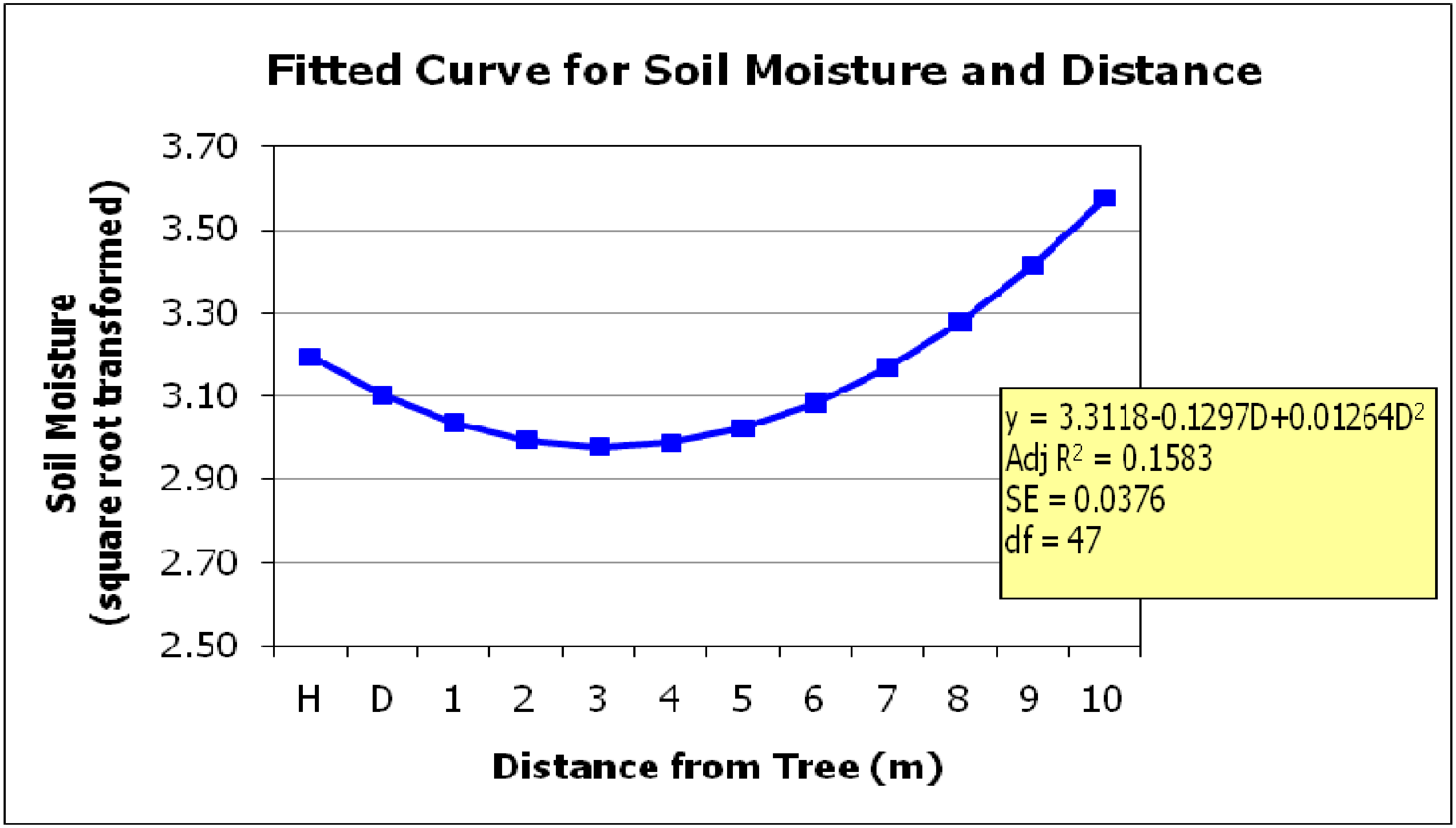

Figure 6. Fitted curve for non-linear regression of soil moisture and distance, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

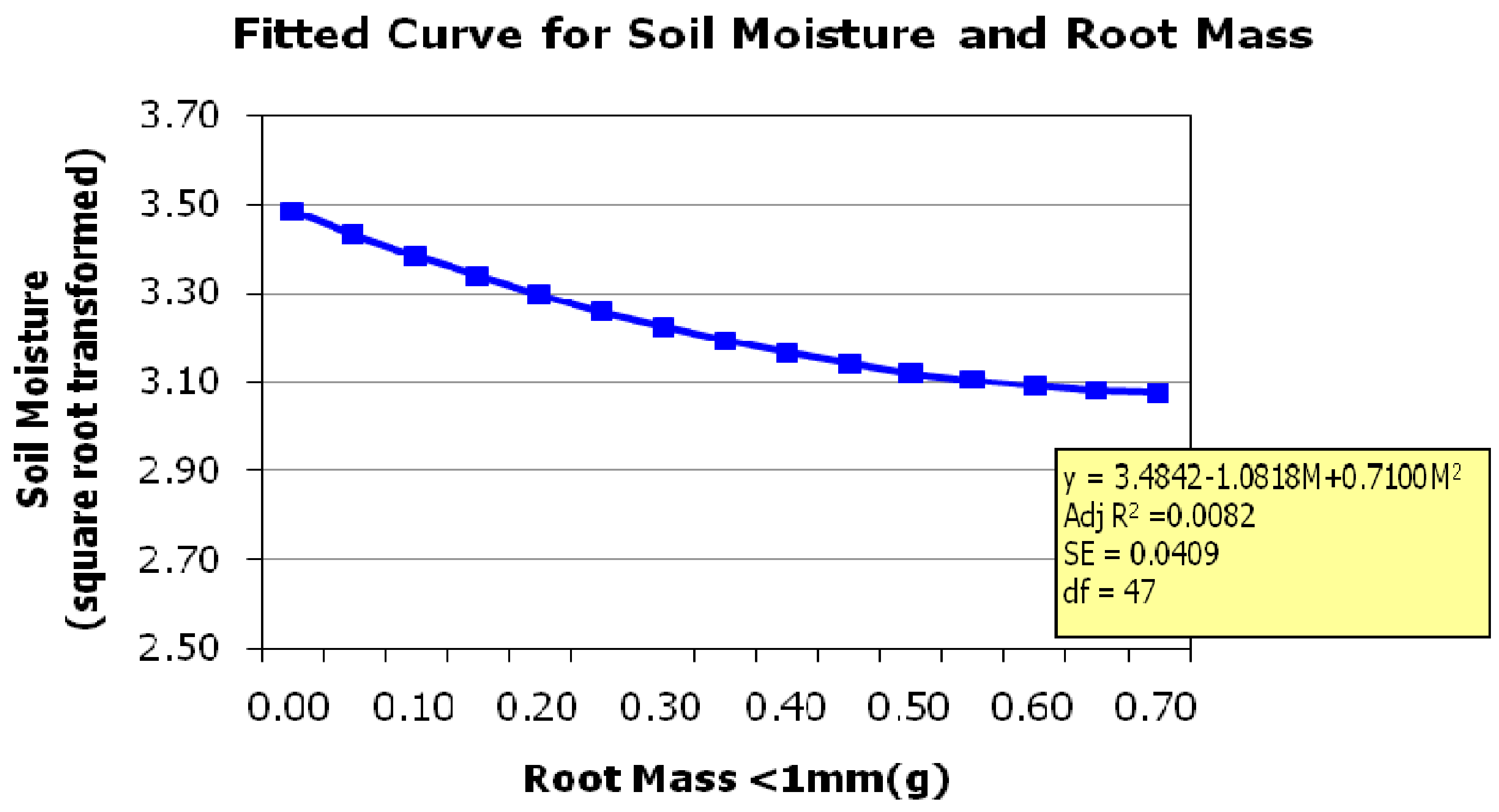

Figure 7. Fitted curve for non-linear regression of soil moisture and juniper root mass, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

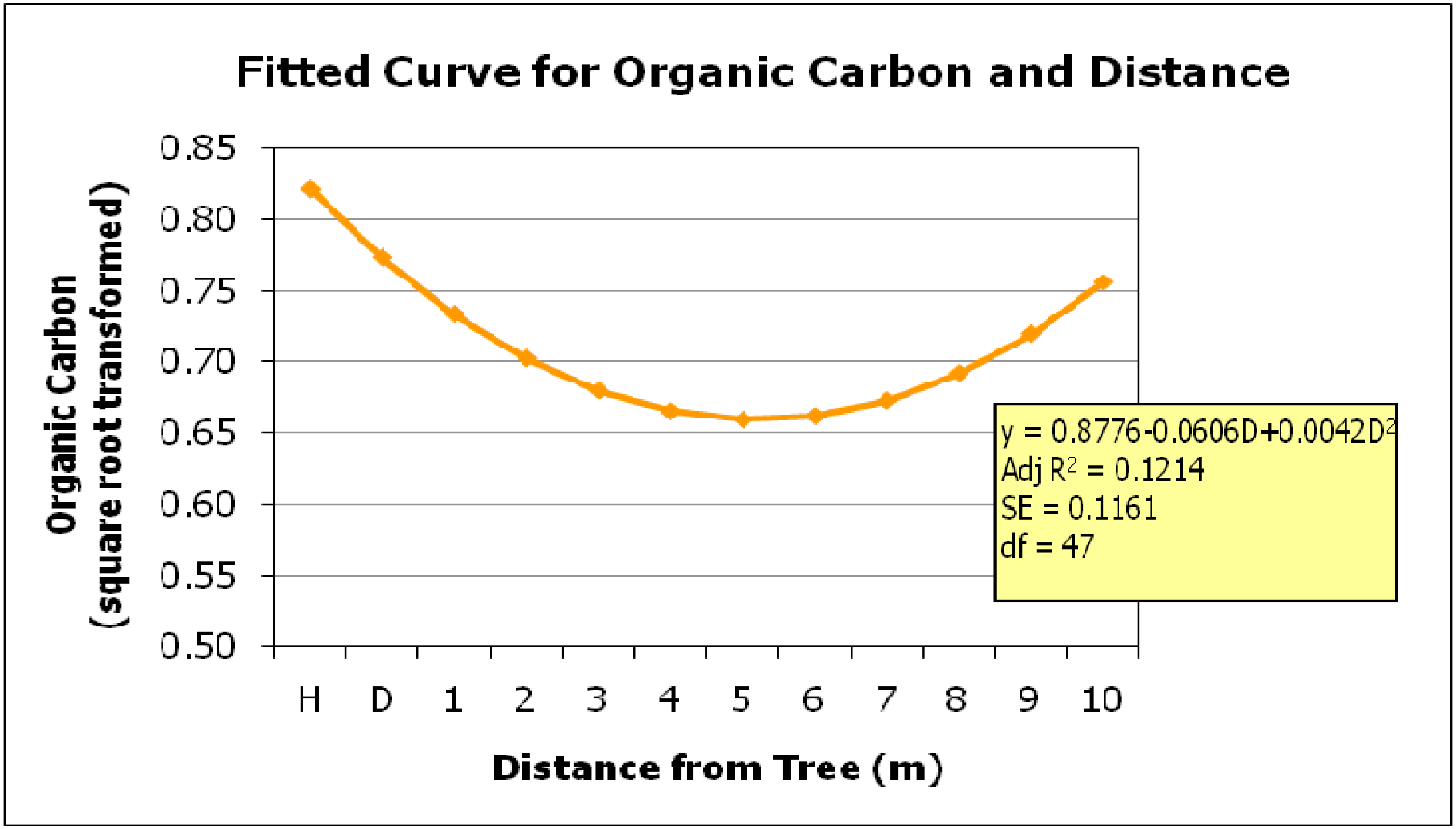

Figure 8. Fitted curve for non-linear regression of organic carbon and distance, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

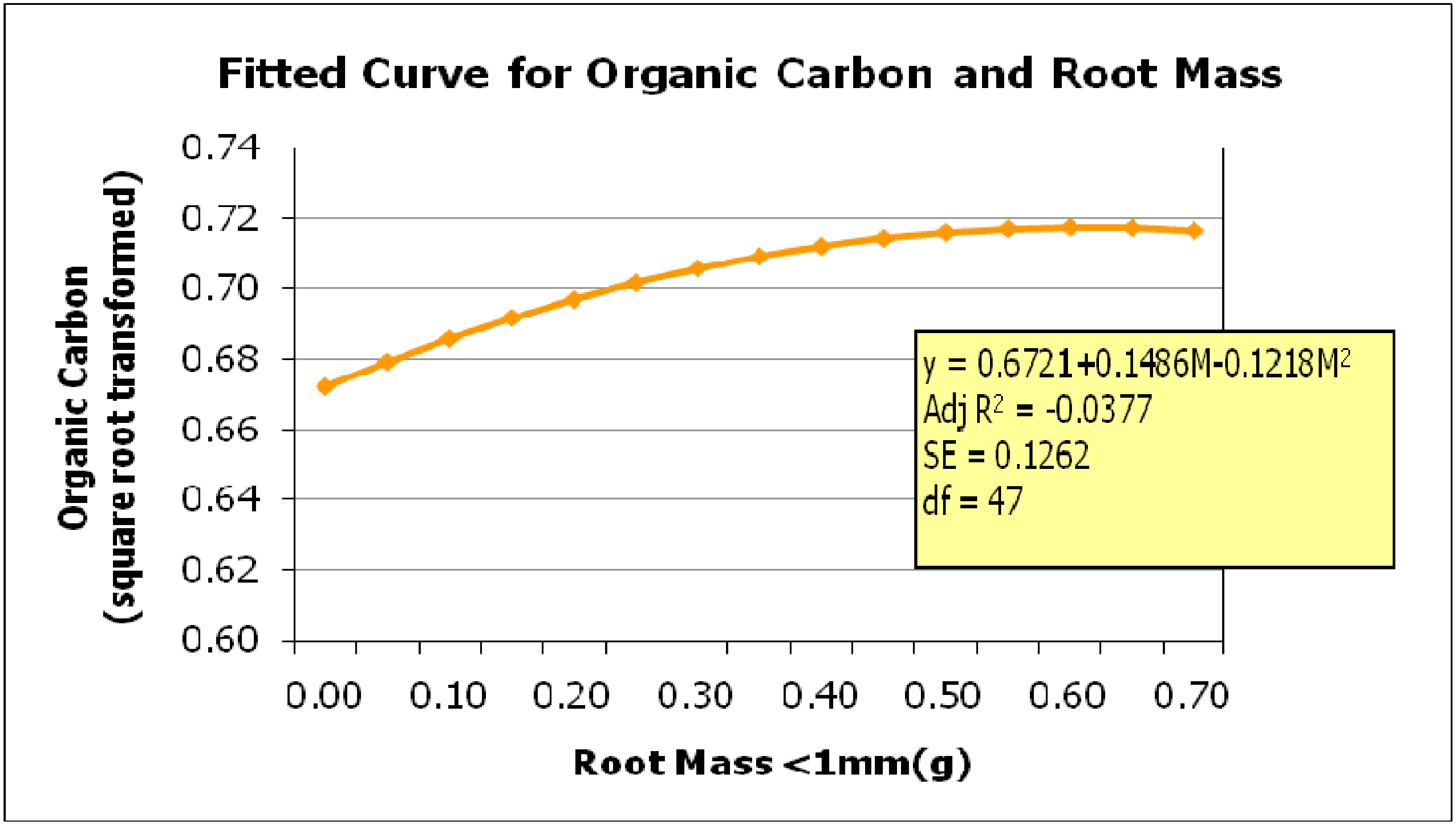

Figure 9. Fitted curve for non-linear regression of organic carbon and juniper root mass, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

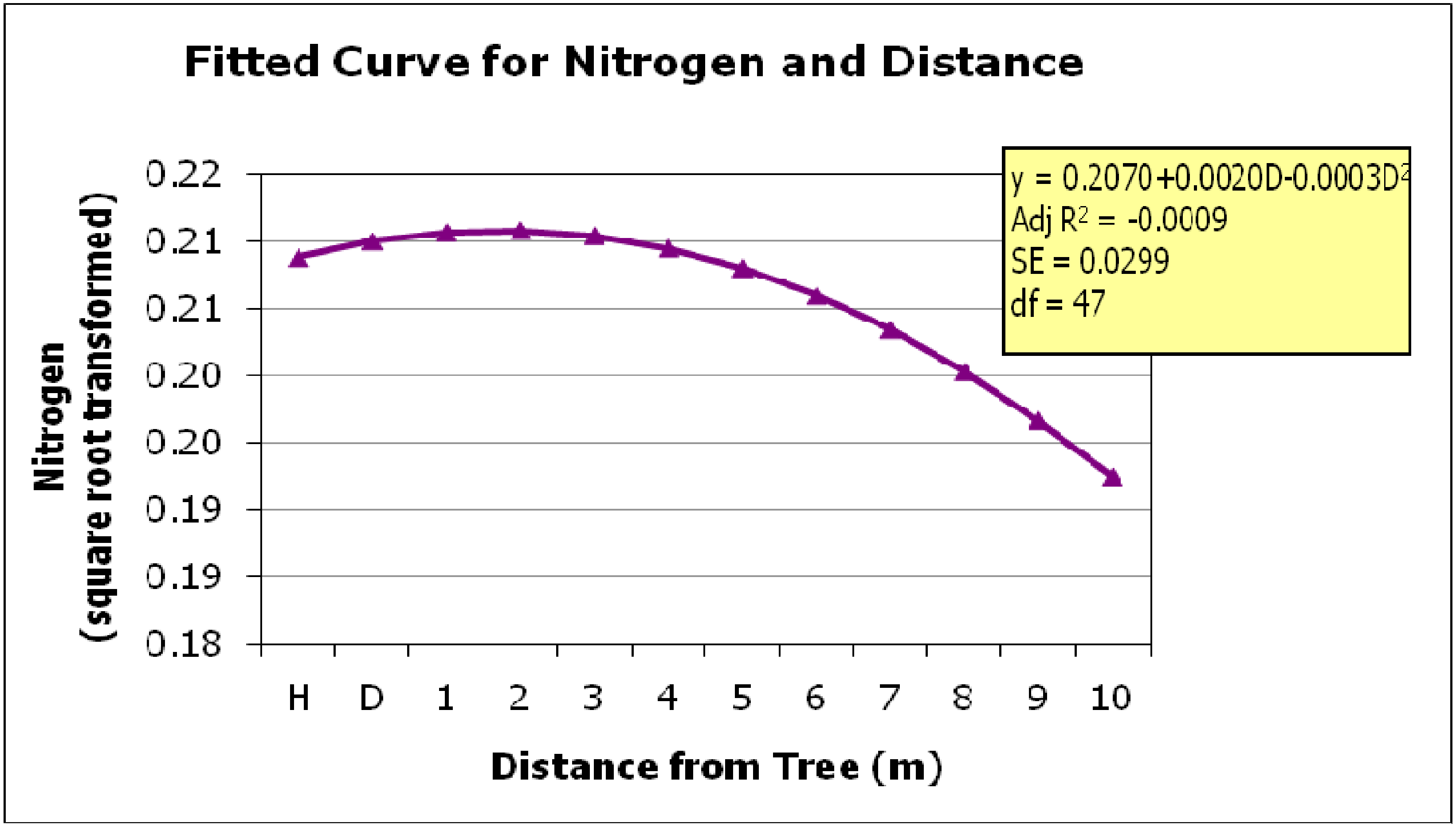

Figure 10. Fitted curve for non-linear regression of total nitrogen and distance, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

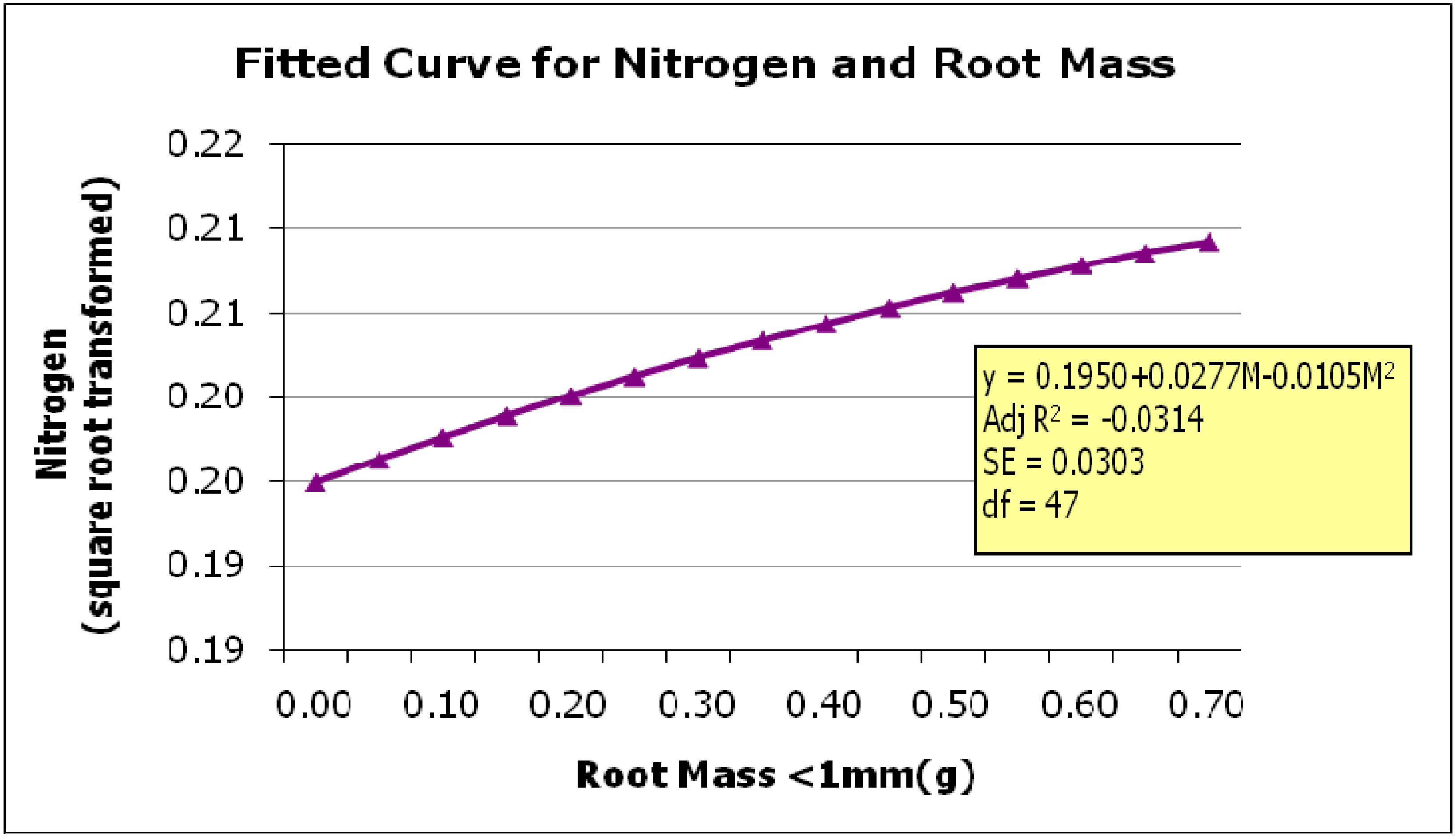

Figure 11. Fitted curve for non-linear regression of total nitrogen and juniper root mss, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

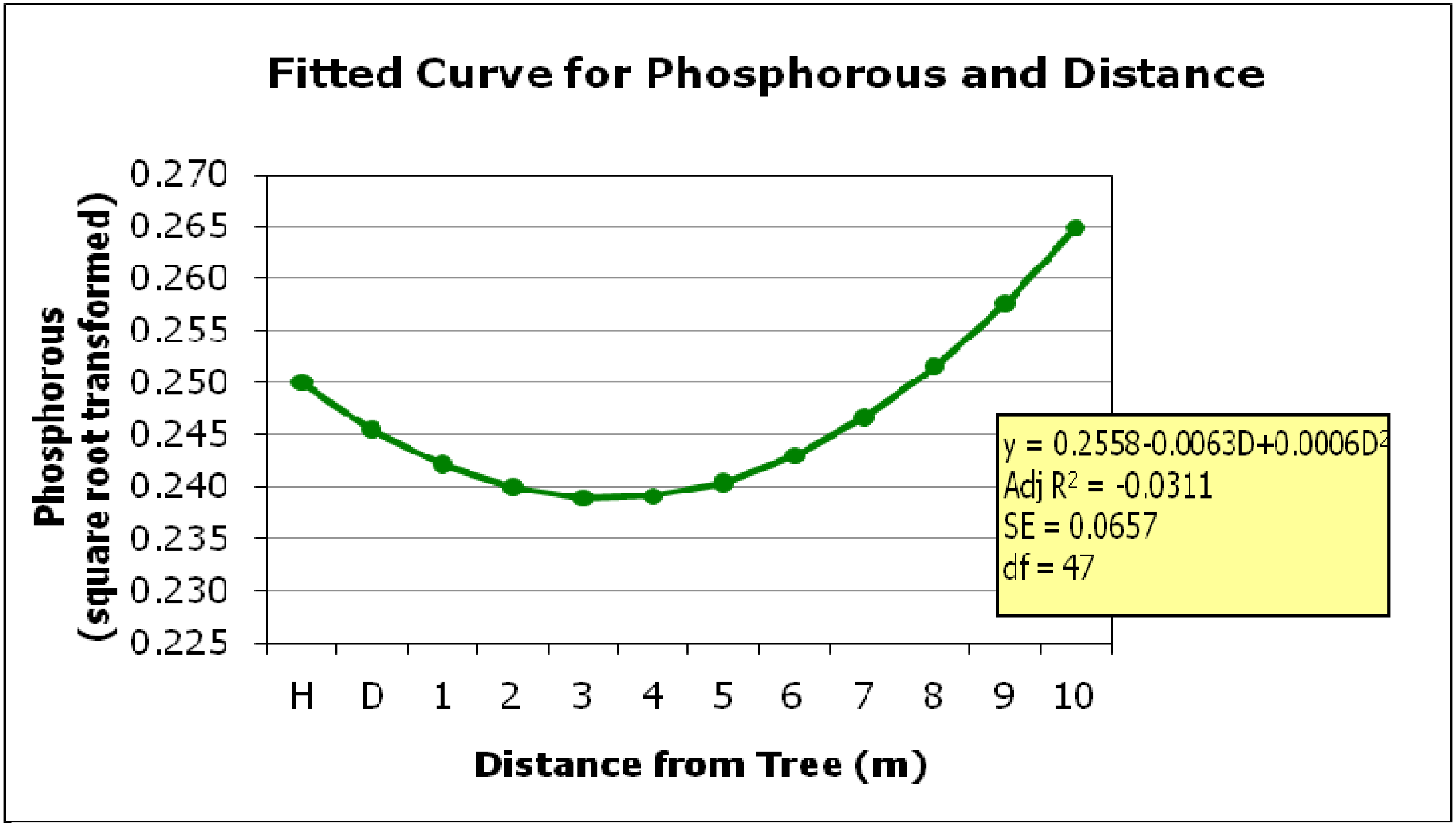

Figure 12. Fitted curve for non-linear regression of extractable phosphorus and distance, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

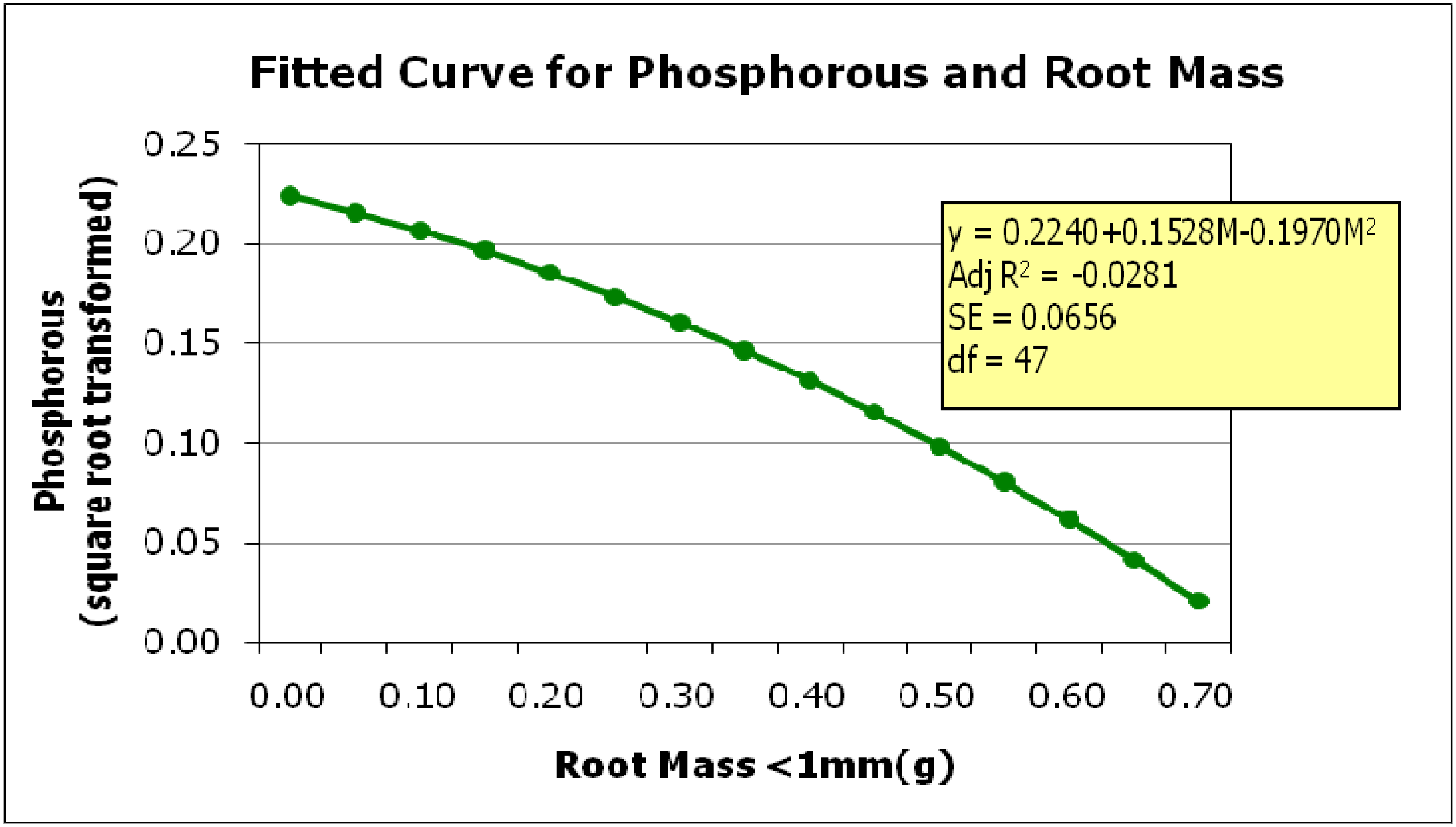

Figure 13. Fitted curve for non-linear regression of extractable phosphorus and juniper root mass, where H is halfway between trunk and dripline and D is canopy dripline, Snowflake, Arizona, February 2009.

DISCUSSION

This study focused on the relationship between juniper trees and surrounding soils. It examined the influence of trees on soil nutrient levels. Results suggest that although juniper trees in this study had no detectable effect on nutrient (phosphorus and nitrogen) levels by distance from the tree, they do have some effect on soil moisture and organic carbon levels.

Juniper root mass demonstrated a significant quadratic relationship with distance. Non-linear regression indicated a significant quadratic relationship (F=7.27, df=47, p=0.002) (Figure 5). Although this is an obvious conclusion to reach, it is interesting to note that of the four trees studied, three had root mass extending more than 10 m past their canopy. With juniper roots extending this far into the interspace, it shows how far lateral roots can extend from juniper trees. This data is similar to results from previous studies (Amiotti et al., 2000), which observed changes in soil pH and exchangeable Ca and Mg, up through a distance of 2 m away from the tree. The quadratic relationship indicates that root mass increases away from the tree, peaks near the 5 m distance, then decreases out to 10 m (Figure 14). Root mass is low near the tree because these small roots have died off and not been replaced. Mass is also low at the farthest distances from the tree because the tree is still actively producing new roots.

Organic carbon had a significant quadratic non-linear relationship to distance (F=5.11, df=47, p=0.010). In regard to root mass though, organic carbon failed to show a significant relationship. The distance relationship data show the peaks of carbon both near the dripline of the tree, and near the end of the transect (Figure 8). The high concentration of organic carbon near the canopy is primarily tree litter. A correlation of the first four samples of each tree (under the canopy, drip line, meter 1 and meter 2) indicates a strong negative relationship (r=-0.567, df=14, p=0.02). The negative r-value indicates that within this 3 m area, a large amount of carbon is located directly under the tree, which quickly decreases past the tree canopy. This may be why there is a closer relationship between carbon and distance, as opposed to root mass; because of the influence of the canopy. However, root mass contributes to this distribution of carbon. It is possible that the carbon levels around the tree are also increased by the presence of large, mature roots. As these roots develop and mature they may slough off organic material which is then decomposed and incorporated into the soil. The increase concentration of carbon may also be a result of continuous regeneration of new roots. The presence of large carbon stores below junipers follows previous conclusions which determined that in more arid environments, carbon is more abundant due to lack of precipitation (Harrington and Williams, 2008). Although residual root material adds carbon to the soil, the data indicate that most of the carbon in the soil is a result of canopy influence. The small increase in carbon near the end of the transect confirms this, as this is where grass cover is highest (Figure 14). At the 8 m mark grass root mass is at its highest level, 0.25 g, indicating the highest grass cover. This increase represents the addition of carbon to the soil from dead grass material which falls and accumulates on the ground.

Soil moisture non-linear regression analysis with distance indicated a significant quadratic relationship (F=5.42, df=47, p=0.007). This increasing soil moisture content demonstrates a potential effect of juniper roots on soil properties. This relationship suggests that an influence of the canopy on soil moisture. The data show that as distance increases away from the tree, and root mass decreases, water availability increases (Figure 6). This is similar to the findings from Madsen et al (Madsen et al., 2008). The fact that there was no significant relationship between root mass and soil moisture indicates that the influence of the tree on the soil is not coming from juniper roots. It should be restated here that this study occurred in the month of February. The results and conclusion of this study may be different if the samples were taken during warmer months.

Lower water availability can have a dramatic effect on soils closer to the tree. Water availability has an effect on the ability of juniper roots to access soil nutrients. If there is low or limited soil moisture, it is difficult for trees to access these nutrients (Wilson and Maguire, 2009). However, the data do not show a significant relationship between water availability and juniper root mass. This indicates that although water availability is increasing with distance away from the tree, it may not be solely the result of the juniper root uptake. Previous soil temperatures in the month of February from this study site indicate soil temperatures ranging from 3.8° C to 5° C (Debnar, 2007). At these temperatures, it is unlikely that juniper trees are able to uptake much soil water (Breshears et al., 1997). Most of the change in soil water levels observed in this study may be the result of the canopy intercepting precipitation which falls near the tree, so there is less precipitation hitting the ground under the tree. Much of this intercepted precipitation is lost due to evaporation or sublimation (Davenport et al., 1996).

The data from this study do not suggest a non-linear relationship between either nitrogen or phosphorus, and root mass or distance. Neither nitrogen nor phosphorus demonstrated a reliable trend on their own. The data for extractable phosphorus (Table 2) indicates an erratic and unpredictable distribution of phosphorus throughout the entire sampling area. Although total nitrogen demonstrates a slightly decreasing trend (Table 2), it is so slight that it is difficult to make a specific determination as to the cause. The nitrogen data do indicate a pattern which shows a decrease to about 6 m from the tree, with a sharp increase at the 9 m mark. This pattern may be a result of increased grass abundance and nitrogen fixation through increased soil enzyme activity (Debnar, 2007). Lack of significant findings for nitrogen and phosphorus indicate that either juniper trees have no influence on these nutrients, or the effect is too small to have been observed in this study.

The issue of experimental scale raises several important considerations at this point. Organic carbon was observed to decrease rapidly with distance from the trees, up to 2 m. Although this pattern was not observed with total nitrogen and extractable phosphorus, the carbon results are consistent with other reported results (Amiotti et al., 2000, Tiedemann and Kiemmedson, 2000, Zinkie, 1962). All of these results show trees having an impact on soils up to a distance of 2 m away from the canopy in a predictable pattern. The carbon results presented in this study confirm this. Most previous studies only measured 2 or 3 m from the canopy, and their pattern of decreasing nutrients was measured in great detail. This study looked at greater distances with more distance between samples. It is possible that this scale may be too large to observe changes in soil nitrogen and phosphorus levels. The changes which have been reported before are generally small in quantity and only occur out a few meters from the tree. It seems that although juniper roots extend a long distance from the tree, their affect on soil total nitrogen and extractable phosphorus levels may occur at different scales. Although carbon availability changes significantly over distance, this is due to additions of carbon. This study was concerned with removal of phosphorus and nitrogen from soil, and the data do not indicate this. It may be that the roots which are the farthest away from the tree simply have not had enough time to extract an observable quantity of nutrients from the soil. It is also possible that nutrient uptake occurred in roots which are larger than 1 mm. The assumption was made that 1 mm and smaller roots would be responsible for most of the juniper uptake because this has been observed in similar tree species. However, this phenomenon has not been observed in junipers, nor received much study. This may be an area where additional research would provide valuable insight. A study which measures nutrient levels at distances from 2 to 5 m from the tree, with samples taken every 10 cm, may confirm if the junipers influence extends beyond 2 m.

The purpose of this study was to describe the bare patches in the grassland at the Snowflake, Arizona site. Since these bare patches were thought to have occurred as a result of decreased levels of extractable phosphorus and total nitrogen, and the results fail to explain the observed bare soil conditions of the site in a statically significant manner, it is important to consider an alternative explanation.

This consideration is pedogenesis. In arid environments such as the Snowflake study site, pedogenesis is generally slower than more humid climates. This slower development results in patchy, discontinuous distribution of soil nutrients (Tiedemann and Kiemmedson, 2000). It is possible that the Snowflake study site is still undergoing early pedogenic development which can create uneven distribution of nutrients, which would make analysis problematic.

Another factor which may affect the results is the accuracy of the analysis equipment. The spectrophotometer used, Thermo Scientific Genesys 20 model 4001/4, has a reported accuracy to within 0.003 ppm (Thermo Scientific Inc., 2009). Since analysis was based upon results that extended into the thousandth ppm, it is possible that the results reported were affected by this limited accuracy. Significant changes in extractable phosphorus may be present, however not detectable due to the limitations of this device. The nitrogen analyzer, Perkin-Elmer 2410, also has limited accuracy in reference to this data. The reported accuracy is <0.3% (Perkin-Elmer Corp, 2010). As all of the total nitrogen results were at the 0.05 level, these results may also not be measured accurately enough to reflect any possible changes or pattern in total nitrogen levels.

The results also need to be discussed in terms of their impact on ecological restoration. The primary concern for restoration ecologists and land managers is mitigation of effects of juniper invasion. The Snowflake site presents a situation where juniper trees appear to be effecting native grass growth in a negative way. The data gathered from this study do not give clear answers to the situation at the Snowflake site, however they do provide insight which may be useful to future restoration projects carried out within juniper grassland areas.

Soil erosion is a problem in these areas which will more than likely result in smaller grassland areas. Erosion can create conditions for which invasive species can move into a grassland and spread. The soil erosion is exacerbated by juniper cover in that understory growth is limited (Tiedemann and Kiemmedson, 2000). This may continue to promote a site which is poor for new grass establishment. With less grass growth, there are also less organic carbon sources for the soil, which can negatively affect aggregate stability. Smaller rainfall events will have a larger impact on erosion rates. The effect of runoff and degraded soil stability will increase in distance from the trees, extending further into the grassland (Tiedemann and Kiemmedson, 2000).

The extensive nature of juniper root expansion is also an indicator of potential problems. As this study and others (Krämer et al., 1996) have demonstrated, juniper roots can extent great distances beyond their canopy, by as much as eight times the diameter of the canopy. Perhaps nutrients which were not analyzed in this study may be affected. The alternating densities of juniper roots and grass roots may indicate competition (Figure 14). Though this study focused specifically on impact of juniper roots, when considered together, grass roots appear to increase in quantity when juniper roots decrease. Although this study failed to determine the exact cause of the bare patch at the Snowflake study site, competition between junipers and grasses seems apparent.

This study examined the potential relationship between juniper trees and surrounding grassland soil nutrient availability. The results demonstrate a slight increase in soil water availability moving away from the tree. It also presented the impact that juniper canopies have on organic carbon levels. The study failed to show relationships between invading juniper root mass and soil total nitrogen or extractable phosphorus. This study also demonstrates the extensive nature of juniper root distribution and potential impacts this can have on soil water. It is possible that, given time, the influence of the juniper trees will increase as their root systems continue to develop.

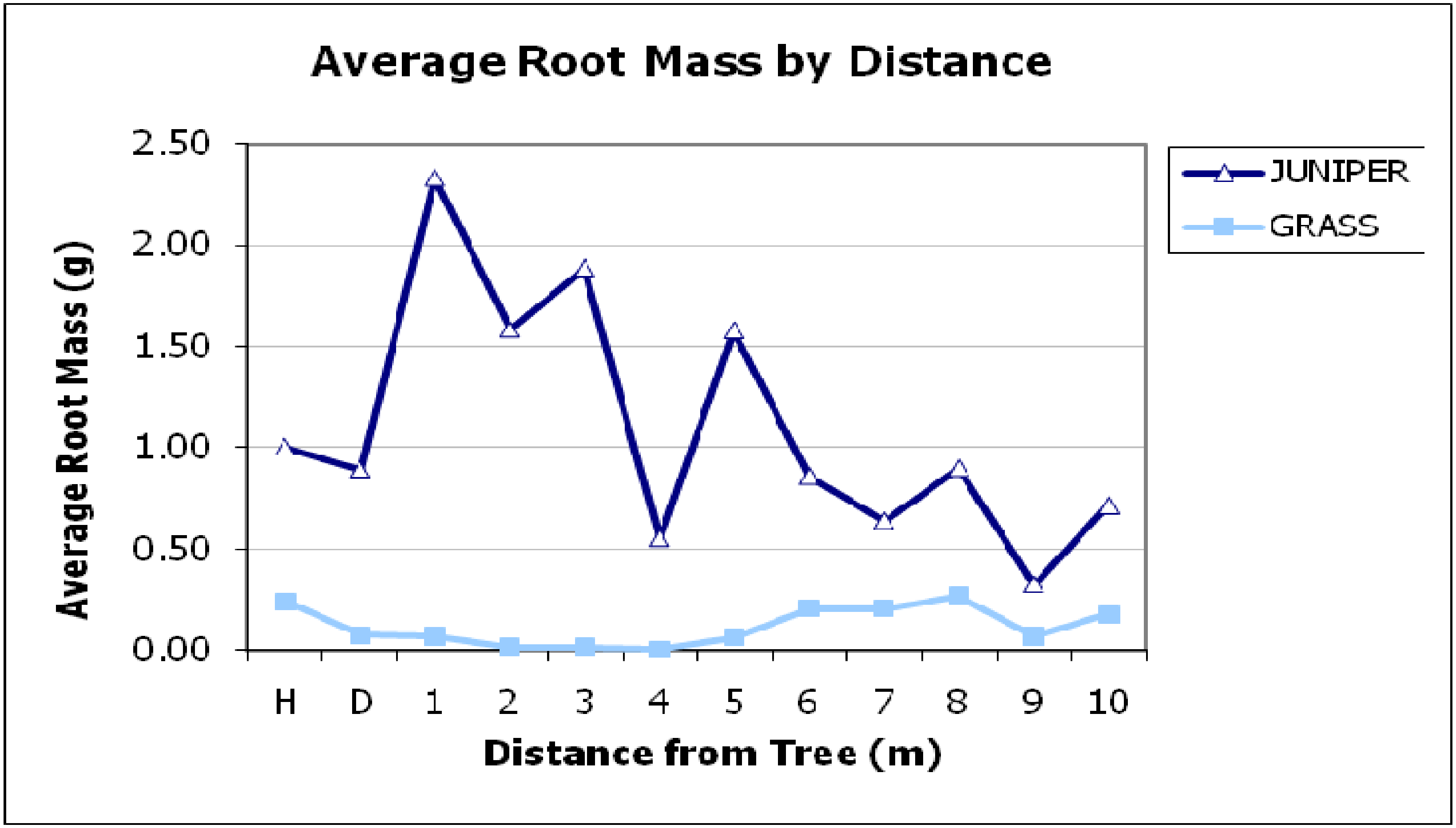

Figure 14. Average mass of all juniper and grass roots (g), where H is halfway between the trunk and canopy and D is the canopy dripline, Snowflake, Arizona, February 2009

Table 2. Averages of raw data indicating juniper root mass, grass root mass, grass cover, soil moisture, total nitrogen, extractable phosphorus and organic carbon, based on distance from juniper tree, Snowflake, AZ, February, 2009.

Dist. from Tree (m)	Juniper root mass (g)	Grass root mass (g)	% Grass cover	% Soil Moisture	% Total N	Extract-able P (ppm)	% Organic Carbon
H	16.4	8.26	10.00	6.66	0.05	0.07	0.93
D	22.3	8.56	3.75	9.88	0.04	0.04	0.47
1	20.9	8.66	3.75	10.08	0.04	0.06	0.43
2	21.5	8.68	0.00	10.23	0.05	0.08	0.50
3	19.6	8.73	0.00	9.81	0.04	0.07	0.41
4	22.6	8.78	2.50	10.28	0.04	0.07	0.49
5	23.5	8.75	7.50	10.18	0.04	0.03	0.42
6	23.8	8.75	11.25	10.63	0.04	0.06	0.50
7	22.2	8.78	47.50	9.90	0.05	0.06	0.53
8	22.6	7.7	21.25	10.43	0.05	0.07	0.59
9	27.3	8.76	53.75	10.83	0.03	0.09	0.47
10	26.8	879	43.75	12.40	0.04	0.04	0.51

CONCLUSION

Influences of juniper trees on nutrient availability in grassland soil were studied to examine two hypotheses. The first hypothesis tested whether there was a relationship between soil nutrients and soil moisture, and distance from the tree. This study found no significant relationship between total nitrogen or extractable phosphorus, and distance from the juniper tree. This study did find a significant quadratic relationship between organic carbon and distance. Also, soil moisture significantly increased with distance away from the tree. There was also a significant increase in soil moisture with increased distance from juniper trees.

The second hypothesis tested if root mass influenced nutrient levels, thus indicating a relationship between available soil nutrients and juniper tree roots. A significant quadratic relationship was found confirming that tree root mass decreases with distance from the tree. There was however no significant relationship between juniper root mass and organic carbon, total nitrogen or extractable phosphorus availability.

Juniper trees have significantly increased their distribution throughout the American West, mostly through former grassland areas (Miller, 1995). This study examined potential impacts on these grassland soils as a result of juniper expansion. The results of this study indicate no detectable decrease in total nitrogen or extractable phosphorus availability resulting from juniper trees mining grassland soils. This study does show increased organic carbon levels resulting from juniper canopy inputs into the soil, as well as decreased soil moisture near the tree as a result of canopy intercession. This study also documents extensive juniper root expansion and potential grass / juniper root interaction.

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APPENDIX A

STUDY SITE PHOTOGRAPHS

A1.

Study site in Snowflake, Arizona, February 2009, showing trees 1, 2 and 3 used for the study, as observed from the grassland. Notice bare area directly in front of the trees.

A2.

Study site in Snowflake, Arizona, February 2009, showing bare area in foreground and grassland. Picture was taken directly in front of study trees looking toward study area, through bare patch into grassland.

A3.

Study site in Snowflake, Arizona, February 2009, showing measurements being taken. Line transect measured from base of tree, through bare area and into grassland.