AUBURN UNIVERSITY

FOREST HEALTH COOPERATIVE

RESEARCH REPORT 2015-02

ASSESSING SOIL DYNAMICS ASSOCIATED WITH *IMPERATA CYLINDRICA* IN ITS RELATION TO LOBLOLLY PINE DECLINE

by
Ben Brunson and Lori Eckhardt

ABSTRACT

Loblolly pine decline is a decline complex associated with root-feeding bark beetle populations that vector ophiostomatoid fungi. These bark beetle populations are attracted to stressed pine trees and can contribute to premature mortality. The water and nutrient content of the soil as well as the availability of water and nutrients to a tree can greatly influence the health and vigor of that tree. In this study, the soil dynamics of a loblolly pine stand in southeastern Mississippi infested with *Imperata cylindrica* was assessed to determine the impact *I. cylindrica* is having on soil chemical and physical properties. Soil nutrient levels were found to be consistently higher in the *I. cylindrica* plots as compared to NCO plots with significantly higher levels for some of the nutrients at some or all of the depths tested. The exact affect that *I. cylindrica* is having on these nutrient concentrations cannot be derived from this study but, it seems that *I. cylindrica* is having an effect on soil physical properties. Soil bulk density, gravimetric water content, and soil strength all are more conducive to root growth in *I. cylindrica* plots which may be due to the constant growth of rhizomes and the slow decomposition of *I. cylindrica* leaf litter.

INTRODUCTION

Exotic species are commonly recognized as one of the major threats to biodiversity and ecosystem stability (Wilcove et al., 1998, Mack et al., 2000) but little focus has been made on the potential impacts by these species to soil processes (Ehrenfeld, 2003). The effects of invasive plants on soil properties can be potentially important to invasion processes, their ecological impacts, and strategies to restore the desired species in those infested areas (Hook et al., 2004). The success that invasive exotic plants have can be improved by their negative or positive effects on the availability of nutrients in the soil (Vinton and Burke, 1995, Saggar et al., 1999, Ehrenfeld et al., 2001). Exotic invasive plants have the potential to alter soil processes including carbon, nitrogen, and water (Duda et al., 2003, Ehrenfeld, 2003). Invasive species can affect the availability of nutrients through their litter inputs and accelerated rates of decomposition and uptake can increase nutrient cycling (Allison and Viousek 2004, Ashton et al., 2005). Increased uptake of nutrients could be driving the higher photosynethetic rates and specific leaf area exhibited by some exotics (Daneshgar and Jose, 2009). Exotic plants alter soil nutrient dynamics by differing from native plant species in biomass and productivity, morphology, phenology, and tissue chemistry (Ehrenfeld, 2003). Available data suggest that exotic invasive plants can exhibit a wide range of effects on soil nutrients even within a single species. Increases (Rutherford et al., 1986; Witkowski, 1991), decreases (Feller, 1983; Versfeld, 1986), or no change in soil nitrogen (Belnap et al., 2001) have been documented to occur due to invasions by plants. Plant invasions by exotics have been shown to affect other soil elements as well, including P, K, Ca, and Mg. A strong positive relationship was found by Howard et al. (2004) between soil carbon (C), phosphorus (P), and magnesium (Mg) and degree of invasiveness for a variety of invading species in New York. Yonekura et al. (2010) reported that soil carbon stock increased by 23% as primary forestland was converted to *I. cylindrica* dominated grassland and this was attributed largely to the organic matter supply by grass roots, rhizomes, and charred materials from wildfires. Invasive plants have also been found to change soil pH levels. Soil pH in invaded areas of New Jersey by *Berberis thunbergii* DC and *Microstegium vimineum* (Trin.) A. Camus was found to be significantly higher than in areas not invaded by these species (Kourtev et al., 1998). In contrast, a study by Scott et al. (2001) found that a *Hieracium* species invading areas in New Zealand, lowered soil pH and mineral nitrogen while increasing total soil carbon and nitrogen. Since grasses generally have shallow root systems, they can reduce the nutrient availability of the uppermost soil layers and when they form dense root systems with significant belowground biomass, they can restrict nutrients to other plants by retaining increased amounts of available nutrients (Daneshgar and Jose, 2009). Fagan and Peart (2004) found the shrub *Rhamnus frangula* (L.) reduced the growth and survival of *Acer rubrum* (L.), *A. saccharum* Marsh., *Fraxinus Americana* (L.), and *Pinus strobus* (L.) in New Hamphsire, which the authors attribute to its extensive shallow root system.

Imperata cylindrica (L.) Beauv. is one of the major species impacting the southeastern forest ecosystem currently. *Imperata cylindrica* can invade a wide range of soil types with a wide range of nutrient concentrations as shown in a study in Mississippi by Bryson et al. (2010). *Imperata cylindrica* appears to grow best in soils with low pH, low fertility, and low organic matter but can range from the coarse sands of shorelines to soils containing > 80% clay of reclaimed phosphate settling ponds (MacDonald, 2004). *Imperata cylindrica* is extremely efficient in nutrient uptake as reported by Saxena and Ramakrishnan (1983). Lippencott (1997) determined that *I. cylindrica* is capable of altering community function of the native Florida sandhill areas by changing vegetation structure, soil processes, resource availability, fire regime, and native seedling recruitment. Daneshgar and Jose (2009) found that *I. cylindrica* alters nitrogen availability to *P. taeda* seedlings and found that the pine seedlings had significantly less nitrogen in their foliage and roots as compared to native competition. Brewer and Cralle (2003) suggested that *I. cylindrica* was a better competitor of phosphorus than native pine savanna plants. A study by Hartemink and O'Sullivan (2001) comparing leaf litter decomposition of *Piper aduncu* (L.), *Gliricida sepium*,(Jacq.) Kunth ex Walp, and *I. cylindrica*, found that *I. cylindrica* leaves had much slower decomposition rates and the soil contained significantly more water, as well as significantly reduced soil nitrogen levels. Daneshgar et al. (2008) found that *I. cylindrica* significantly reduced productivity and growth of an established *P. taeda* stand with only 26% survival in plots with *I. cylindrica* competition; pine seedlings were observed to have significantly smaller root collar diameters. The authors suggest that these results may be explained by reduced amounts of foliar nitrogen and water stress to the pine seedlings due to competition of *I. cylindrica.* Several studies have focused on the impact of *I. cylindrica* on pine regeneration but little is known about the impact *I. cylindrica* has to an established pine plantation. *Imperata cylindrica* could be significantly limiting nutrient availability and altering soil physical properties to established pine and consequently reducing the productivity of the pine. The purpose of this study was to compare the impacts *I. cylindrica* is having on soil chemical and physical properties of areas with and without *I. cylindrica* within an established pine plantation to determine if *I. cylindrica* could potentially be a stressor associated with Loblolly Pine Decline.

MATERIALS AND METHODS

Site Description

The research site was located on The Westervelt Co. land east of Leakesville, Mississippi. Twenty plots were established by visually assessing the presence and density of *I. cylindrica* leaf area. Ten plots were established in areas containing heavy infestation of *I. cylindrica* (CO plots) while the remaining ten plots were established in areas containing no infestation of *I. cylindrica* (NCO plots). Plot dimensions were 15.24 m^2 (50 $ft.^2$) in length and the center of the plot located half the distance diagonally across the plot. A metal tag was attached to each center pole denoting the plot identification. *Imperata cylindrica* plots were labeled as C1- C10 while plots without *I. cylindrica* were labeled NC1- NC10. The location (Chapter 2 Table 2.1) and elevation of each center pole was mapped using a handheld geographical positioning system device (Garmin GPSMAP 76Cx, Garmin International Inc., Olathe, KS). Each tree within each plot was assigned a number and a metal tag with this number was attached to the tree at breast height (approximately 137 cm from ground level).

Plot NC4 and all of the plots east of there (C4, C5, C7, C9, C8, C10, and NC3) are located on 18-year old plantation while the remaining plots (C1, C2, C3, C6, NC1, NC2, NC5, NC7, NC8, NC9, and NC10) are located on a 13-year old plantation (Figure 3.1). Both plantations were managed similarly with both receiving fertilization treatments of 36.7 kg/ha of urea (46-0-0 NPK) with the 18-year old stand receiving this in 2007 and the 13-year old stand in 2011 (Ken James, personal communication).

Soil Sampling

The soil series was identified as Benndale sandy loam on 8 to 15% slopes, and Benndale sandy loam or McLaurin sandy loam on 2 to 5% slopes. Benndale soils are classified as a coarse-loamy, siliceous, semiactive, thermic Typic Paleudults and McLaurin soils are classified as a coarse-loamy, siliceous, subactive, thermic Typic Paleudult. These are well drained soils and well drained soils are generally nutrient poor soils due to having low amounts of organic matter and clay which help maintain a higher CEC and slow water infiltration thus reducing leaching of the nutrients (Soil Survey Staff, 2012).

Three- 60 cm long by 5 cm diameter soil cores were sampled on each plot. Each sample location was also plotted on a handheld GPS device (Garmin GPSMAP 76Cx). Each soil sample was divided into 10 cm sections and then further divided into halves. One half of each 10 cm section was weighed and oven dried at 105°C for 48 hours, while the remaining half of each section was weighed and was allowed to air dry. Bulk density and gravimetric soil moisture were calculated in the Forest Health Dynamics Lab as described in Soil Survey Laboratory Staff, 2004, while nutrient analyses were performed by the Soil Characterization Lab at University of Missouri. Samples from each depth segment were composited for each plot, sifted through a 2 mm sieve, and processed for pH via 1:1 water plus 1:2 0.1 M $CaCl_2$ method (McLean, 1982) and % total nitrogen (N_{tot}), % organic carbon (C_{org}), and % inorganic carbon (C_{inorg}) and % total carbon (C_{tot}) via combustion analyzer (Bremner, 1996). The Mehlich-3 procedure (Mehlich, 1984) was also used to determine the quantity of available Phosphorus (P), Potassium (K), Aluminum (Al), Magnesium (Mg), Manganese (Ma), Calcium (Ca), Zinc (Zn), Molybdenum (Mo) and Iron (Fe). Three penetrometer insertions were also taken using a Rimik CP20 cone penetrometer around each soil sample site (9 total for each plot) to measure soil strength levels (Mulqueen et al., 1977).

Statistical Analysis

Soil nutrient levels were averaged within each plot by soil depth segment (0-10 cm, 11-20 cm, and 21-30 cm) and the means of CO plots and NCO plots compared to each other using Tukey's Studentized Range test (PROC GLM; SAS 9.2). Since nitrogen fertilization was performed at different years between the two stands, the nitrogen means were analyzed by stand age and by treatment with a stand age co-variable to see if there was an effect of the different fertilization times to the current nitrogen levels. Soil moisture and bulk density levels were also averaged for each plot by soil depth segment (0-10 cm, 11-20 cm, etc.) and CO and NCO plot means were compared using Tukey's Studentized Range test (PROC GLM; SAS 9.2). Soil strength data were averaged per plot by soil depth (2.5, 5, 7.5,…30cm) and CO and NCO plot means were plotted using Microsoft Excel. The slope and intercept of each linear regression line for each plot were determined and the means CO and NCO plots were compared using Tukey's Studentized Range test (PROC GLM; SAS 9.2).

RESULTS

A comparison of means between CO plots and NCO plots of C_{tot}, N_{tot}, C:N ratio, and pH by water and salt are included in Table 3.2. There was no C_{inorg} found so C_{org} and C_{tot} are equal. There were significantly higher C_{tot} levels throughout the top 30 cm of soil in CO whereas N_{tot} was not different in the top 10 cm but was significantly different in the CO plots from 11 to 30 cm of soil. There was no difference found in the C:N ratio throughout the 30 cm of soil tested. The pH_{H20} and pH_{Na} both showed a trend of having higher values in the CO plots but pH H_20 was only significantly higher at 21-30 cm of soil.

Mean comparisons of base cations as well as the total of base cations, Al, and effective cation exchange capacity (ECEC) between CO and NCO plots are shown in Table 3.3. All base cations (Ca, K, Mg, and Na) had higher quantities in the CO plots compared with NCO plots. Ca was significantly higher in the CO plots throughout the entire profile, K was higher in the upper 20 cm, and Mg and Na were higher in the upper 10 cm. Overall, total base cations were found to be significantly higher in the lower 20 cm. Aluminum was not found to be significantly different between CO and NCO plots but had higher means in the top 10 cm in the CO plots. The ECEC also showed a similar trend as there was no significant difference in the entire 30 cm of soil. Comparison between CO and NCO plots of the means of other available nutrients including P, B, Cu, Mn, Zn, and Mo are shown in Table 3.4. Mean quantities of P were found to be higher in the CO plots but only significant in the 11-20 cm soil depth. Boron levels in the NCO plots were found to be below detection levels (<0.01 ppm) so a comparison was not performed. Elevated levels of Cu in the CO plots did not result in significant differences but Mn level were found to be significantly higher in the CO plots in the upper and lower 10 cm segments. Zinc was found to be significantly higher in CO plots in the upper 10 cm of soil and Mo levels were found to be significantly higher in the middle 10 cm of soil only.

Figure 3.2 depicts mean BD of soils in CO and NCO plots through the top 60 cm. Bulk density was significantly higher in the NCO plots for the top 10 cm of soil but the BD tended to become higher in CO plots deeper into the soil profile. Figure 3.3 shows the comparison of the GMC at each 10 cm segment depth between the CO and NCO plots. The GMC had an opposite trend as the bulk density in which it was found to be significantly higher in the top 20 cm of the CO plot versus the NCO but tended to become more prevalent in the lower portions of the NCO soil profile. Figure 3.4 shows the soil strength linear slope comparison between CO and NCO means through the upper 60 cm of soil. There was a significant difference found between the slopes of the linear regression lines and the graph shows that the soil strength was consistently higher in the NCO plots through the upper 20 cm.

DISCUSSION

No stand or stand x treatment effect on N levels suggests that the fertilization application time differences had no effect on nutrient differences between CO and NCO plots. Since the 13 year old stand had been fertilized more recently we expected to see higher N content in the soil of the NC plots but actually found the opposite with N levels being higher in the CO plots which suggests that other factors are causing the difference. Higher total soil N levels in CO plots at all depths would typically be beneficial to the standing loblolly pine growth but significantly less N was found in the foliage (Chapter 4) of these plots which may indicate that the *I. cylindrica* is limiting the available N to the pine in infested areas. Daneshgar and Jose (2009) also found a similar result in which pine seedlings grown in *I. cylindrica* competition had significantly less N in their foliage as compared to seedlings grown in area of native competition and vegetation free areas. Yonekura et al. (2010) found that after conversion of forestland to *Imperata cylindrica*, soil C stock increased by 23% due to increased grass roots, rhizomes, and charred material from wildfires. Collins and Jose (2008) reported lower soil pH levels in *I. cylindrica* infested stands compared to non-infested stands in longleaf pine ecosystem which is the opposite than found in this study as pH was significantly higher at 21-30 cm soil depth. Ehrenfeld (2003) reviewed the literature looking at the effect of 53 species of exotic plant invasions on soil nutrient cycling processes and found that increases and decrease in soil pH by exotic invasions occurred in equal numbers. The author also suggests that increases in pH may be due to the preferred uptake of nitrate as N source or increased base cation concentrations in the litter. The higher CEC levels we observed in the CO plots may suggest that *I. cylindrica* litter decomposition is leading to slightly higher pH levels in the soil due to the decrease in available cations because of fewer H^+ ions to push cations into the soil solution. The consistently higher base cation levels found in the CO plots explain why the CEC is significantly higher in CO versus NCO plots. This was mostly attributable to the high levels of Ca found in the CO plots with respect to the other cations. There is little research that has focused on the impact *I. cylindrica* has on levels of soil P, B, Cu, and Mn. Research by Brewer and Cralle (2003) suggests that *I. cylindrica* maybe a better competitor for phosphorus than are native pine-savanna plants. Phosphorus is most limiting on very poorly to poorly drained sites and applications of P early in the rotation can increase growth of pine throughout the entire rotation

Plants tend to decrease the bulk density of the soil through root channeling and litter deposition, making water and root penetration easier (Tiedmann and Klemmedson, 1986, Callaway et al., 1991, Joffre and Rambal 1993). The extreme growth of the rhizome network that *I. cylindrica* exhibits could be disturbing the soil at a much higher rate than native plant species and therefore decreasing soil bulk density in the top 10 cm of the soil profile. The higher litter deposition of *I. cylindrica* leaves may be contributing to this lower bulk density in CO plots. This could be an explanation of why gravimetric soil moisture content was higher in the top 20 cm of soil. Hartemink and O'Sullivan (2001) found significantly more water under *I. cylindrica* leaf litter due to the relatively slow decomposition of the leaves. The trends found in this study for soil strength in the upper 18 cm suggest that root growth shouldn't be limited. A study by Zou et al. (2001) found that root elongation rate of Radiata pine decreased exponentially with increasing soil strength and decreased by half its maximum rate at a penetrometer resistance of 1.3 MPa. Even though there was a lower soil strength value throughout the root growth zone of the CO plots, which means a more conducive environment for root growth, we found that fine root weight of loblolly pine in the CO plots was significantly lower in these plots. The fact that the soil nutrient contents are higher in cogon plots, soil moisture content is higher in cogon plots, soil strength is lower in cogon plots, and bulk density is lower in cogon plots all are more conducive values for fine root growth and yet we found fewer fine roots suggesting that there is a significant amount of mechanical hindrance exerted by the *I. cylindrica* rhizomes on the growth of pine roots.

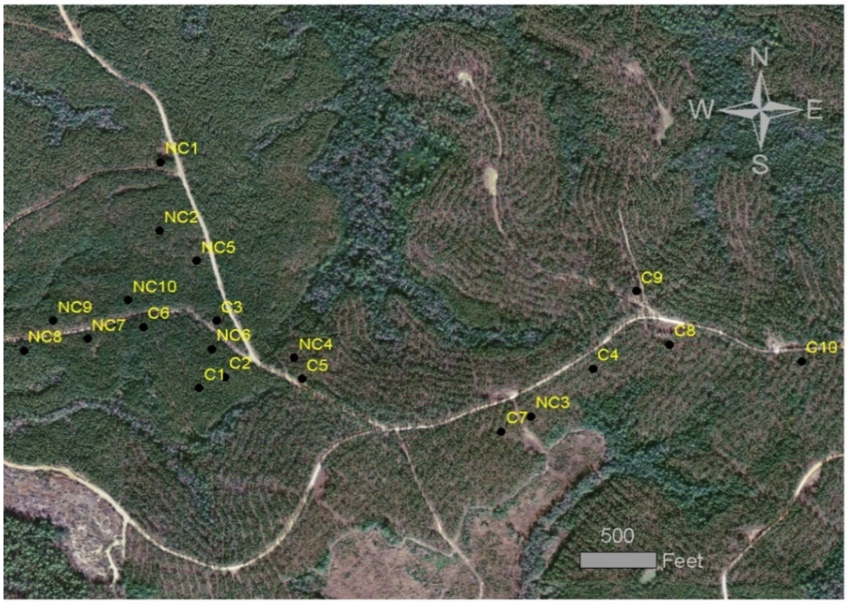

Figure 3.1. Map of plot distribution. C1-C10 are *Imperata cylindrica* (CO) plots, and NC1-NC10 are plot without *Imperata cylindrica* (NCO)

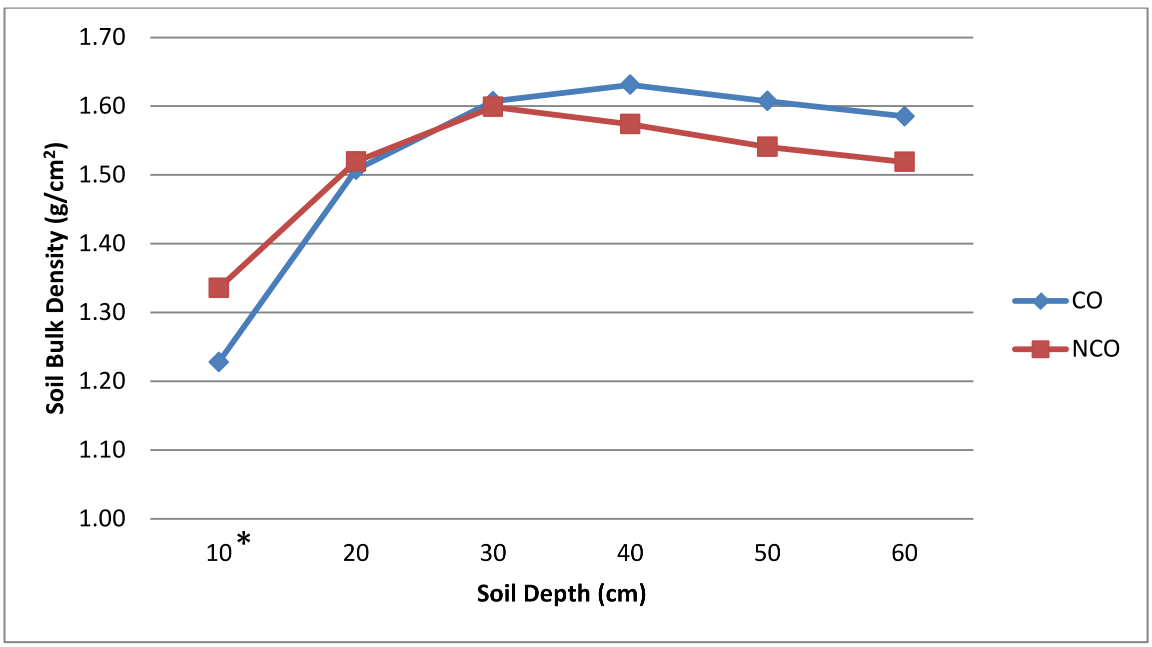

Figure 3.2. Soil bulk density comparison between CO and NCO plots
*NCO bulk density mean significantly greater than CO mean ($p<0.1$), Cv=9.3

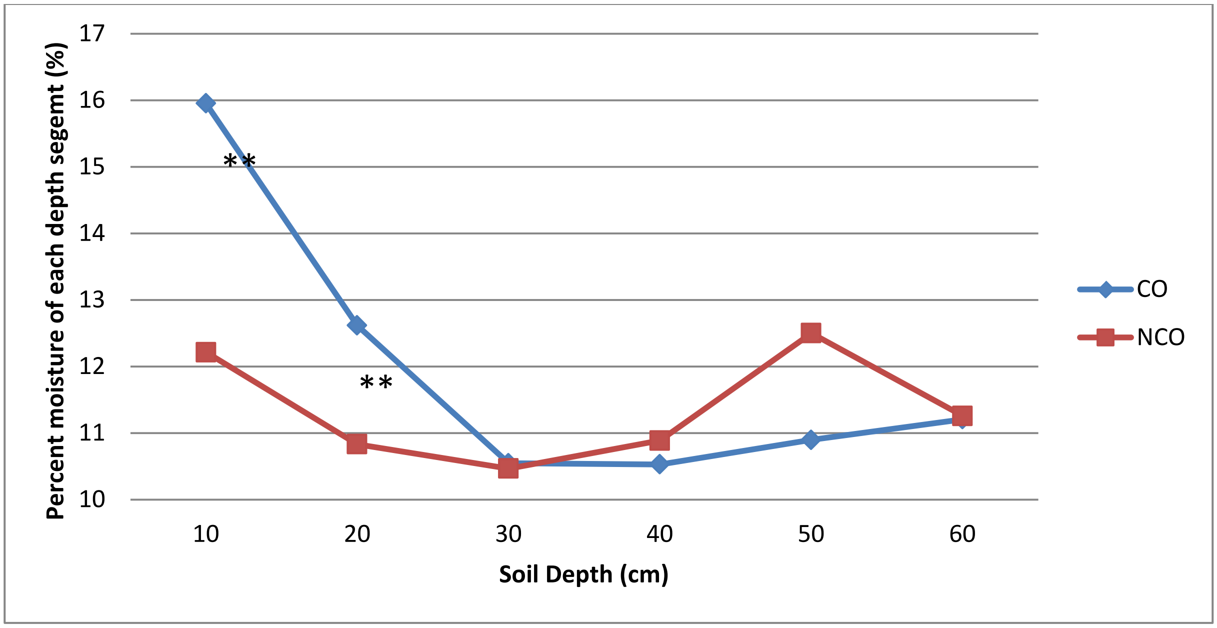

Figure 3.3. Gravimetric water content in the top 60 cm of soil for CO and NCO plots
**CO mean significantly greater that NCO mean p<0.05

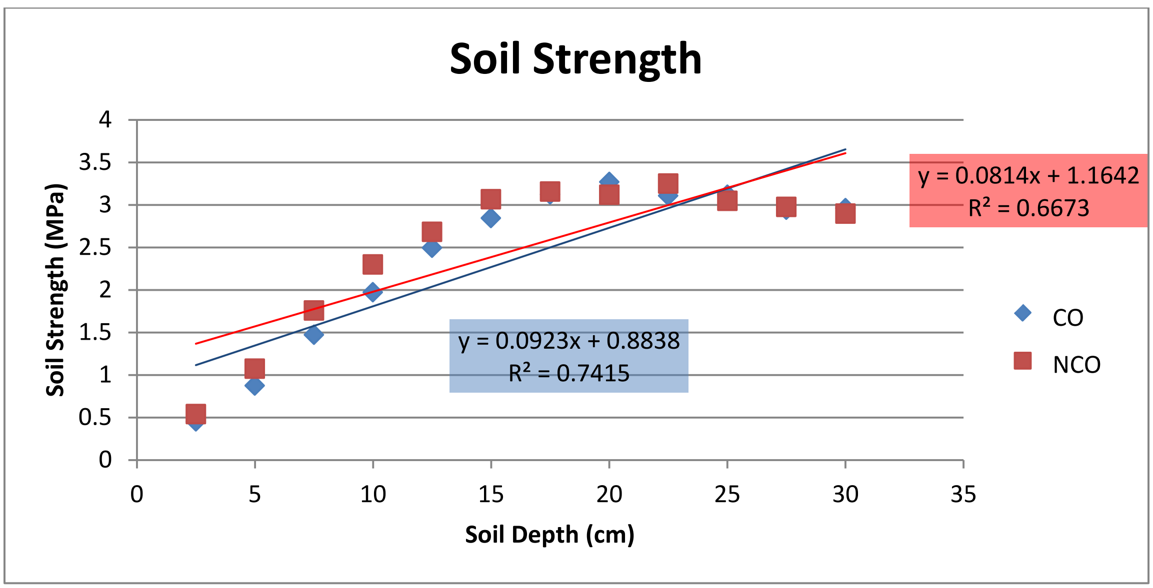

Figure 3.4. Soil strength mean slope and intercept comparison between CO and NCO means

Table 3.1. Comparison of CO and NCO soil chemical content means by soil depth.

Soil Depth (cm)	Total Carbon (%)		Total Nitrogen (%)		C:N Ratio		pH $_{H2O}$		pH $_{Salt}$	
	CO	NCO	CO	NCO	CO	NCO	CO	NCO	CO	NCO
0-10	1.61** (18.85)	1.16	0.058	0.044	27.99	26.67	5.02	4.88	4.34	4.18
11-20	0.766** (36.3)	0.539	0.0322* (27.1)	0.025	23.28	22.03	5.21	5.06	4.40	4.34
21-30	0.362** (33.4)	0.0262	0.0193** (22)	0.015	18.59	16.62	5.27* (2.9)	5.05	4.45	4.26

Mean (coefficient of variation) presented
* significant at P<0.10 level
** significant at P<0.05 level
*** significant at P<0.0001 level

Table 3.2. Comparison of CO and NCO soil cation means by soil depth

Soil Depth (cm)	cmol(+)/kg													
	Calcium		**Potassium**		**Magnesium**		**Sodium**		**Total Base Cations**		**Aluminum**		**ECEC**	
	CO	NCO	CO	NCO	CO	NCO	CO	NCO	CO	NCO	CO	NCO	CO	NCO
0-10	0.68** (65.4)	0.29	0.05** (31.7)	0.03	0.21* (55)	0.13	0.09** (28.1)	0.06	1.00	0.48	4.54	4.48	5.53	4.98
11-20	0.48** (81.8)	0.18	0.03* (37.1)	0.02	0.10	0.07	0.08	0.06	0.69** (48.8)	0.33	4.94	5.00	5.63	5.34
21-30	0.37** (69)	0.14	0.02	0.02	0.10	0.08	0.07	0.07	0.51** (43.7)	0.33	4.71	5.23	5.22	5.56

Mean (coefficient of variation) presented
* significant at P<0.10 level
** significant at P<0.05 level
*** significant at P<0.0001 level

Table 3.3. Comparison of CO versus NCO soil available nutrient means by soil depth

Soil Depth (cm)	Available nutrients (mg/kg)											
	Phosphorus		Boron		Copper		Manganese		Zinc		Molybdenum	
	CO	NCO	CO	NCO	CO	NCO	CO	NCO	CO	NCO	CO	NCO
0-10	17.99	14.85	0.56	BDL	0.80	0.51	64.1** (82)	53.2	0.94** (56)	0.38	2.22	1.75
11-20	10.09** (55.9)	2.72	0.43	BDL	0.55	0.44	56.46	49.52	0.36	0.22	2.60* (44)	1.59
21-30	8.07	5.56	0.3	BDL	0.38	0.35	46.51* (105.8)	42.07	0.36	BDL	2.05	1.38

Mean (coefficient of variation) presented
* significant at P<0.10 level
** significant at P<0.05 level
*** significant at P<0.0001 level
BDL-Below Detection Levels