CHANGES IN SOIL CARBON AND NITROGEN ASSOCIATED WITH SWITCHGRASS PRODUCTION

A Thesis

by

PORFIRIO JOSE LOBO ALONZO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2004

Major Subject: Agronomy

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Approved as to style and content by:

Frank M. Hons (Chair of Committee)	David A. Zuberer (Member)
Michael Sherman (Member)	Mark A. Hussey (Head of Department)

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ABSTRACT

Changes in Soil Carbon and Nitrogen Associated
with Switchgrass Production. (August 2004)
Porfirio José Lobo Alonzo, B.Sc., Escuela Agricola Panamericana (Zamorano)
Chair of Advisory Committee: Dr. Frank M. Hons

Greater knowledge of the short- and long-term effects of biomass production practices on soil biological and chemical properties is needed to determine influences on sustainable land management. Soil samples under switchgrass (*Panicum virgatum* L.), other forage grasses, cultivated crops, and forest were collected seasonally at six locations. Soil organic C (SOC), total N, soil microbial biomass C (SMBC) and N (SMBN), soil mineralizable C and N, and basal soil respiration (BSR) were in general greatest under long-term coastal bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture (>40 years), second highest under Alamo switchgrass and kleingrass (*Panicum coloratum L*.) planted in 1992 and forest, followed by Alamo switchgrass planted in 1997, and was lowest under the cultivated soils. Soil organic C at 0-5 cm was 42-220% greater in soils under Alamo switchgrass planted in 1992 than cultivated soils, except at College Station where SOC values under Alamo planted in 1992 and the cultivated rotation were not significantly different. Although the rotation treatment is cultivated at this location, two high residue crops are used, wheat (*Triticum aestivum* L.) and sorghum [*Sorghum bicolor* (L.) Moench.]. Similar trends were noted for total N, SMBC, SMBN, mineralizable C and N, BSR, and the ratio of SMBC/SOC. Insufficient information was collected in this study to determine whether the parameters evaluated for forest and switchgrass were different. In addition to its high yield potential, adaptation to marginal sites and tolerance to water and nutrient limitations, switchgrass appeared to be a competitive crop in terms of land sustainability, resulting in enhanced soil quality characteristics compared to long-term cultivated soils.

DEDICATION

First of all to God, to my father Porfirio Lobo Sosa, to my children Porfirio, Raúl, Joselina, José Francisco, Alejandro, and Flavia Rosana, to the memory of my grandparents Porfirio José Lobo López and Rosa Sosa de Lobo, and to my wife Flavia García de Lobo.

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CHAPTER I

INTRODUCTION

Extensive research involving woody and herbaceous biomass for energy production has been conducted for at least 20 years. Switchgrass (*Panicum virgatum* L.) has been examined over the past decade as an energy crop, with generally positive results (Sanderson et al., 1996). Switchgrass, a warm season perennial grass native to much of North America and a major component of the tall grass prairie, may have potential as a bioenergy (harvested and burned as a solid fuel for energy production) crop (Zan et al., 1997; Bransby et al., 1998). Bioenergy crops include species with high rates of annual primary production that can be harvested for the production of fuels. The annual above ground net primary production of switchgrass ranging from 17 to 35 Mg ha^{-1}, and switchgrass might provide the basis for an economically viable biomass-to-energy industry in the southeastern United States (Bransby and Sladden, 1991). Switchgrass was selected for development as a bioenergy feedstock because of its high yield potential, adaptation to marginal sites, and tolerance to water and nutrient limitations. Switchgrass has also become an increasingly important forage crop because it is productive during the hot summer months when cool-season grasses are relatively unproductive (Moser and Vogel, 1995). The most important dry matter constituents for a herbaceous biofuel feedstock are lignocellulose, N, and ash. While high levels of lignocellulose are desirable for chemical and biofuel production (Trebbi, 1993), high levels of N and/or ash reduce chemical output in thermochemical conversions (Agblevor et al., 1992).

Switchgrass grown for energy offers dual benefits in efforts to ameliorate increasing atmospheric CO_2 concentrations: (i) replacement of fossil fuels and (ii) the possibility of carbon sequestration (Bransby et al., 1998).

This thesis follows the style of the Soil Science Society of America Journal.

Potential additional benefits of fast-growing bioenergy crops include the possibility of increasing stocks of soil organic carbon (SOC) (Garten and Wullschleger, 1999). Over time, increased SOC storage might help lessen the continuing increase in atmospheric CO_2 concentrations from fossil fuel burning. Fisher et al. (1994) claimed that introduced pastures of deep-rooted grasses in South American savannas help offset the effect of anthropogenic CO_2 emissions. Switchgrass is a deep-rooted perennial grass that has high potential for increasing SOC storage on sites depleted of SOM through cultivation (Zan et al., 1997). Native switchgrass stands have an extensive root system with numerous coarse roots that extend to soil depths of ≈ 3 m (Weaver and Darland, 1949). It is expected that switchgrass through its extensive root system might contribute to soil carbon sequestration and improvement of soil quality through the formation of soil organic matter (SOM), and thereby represents a means for increasing SOC storage.

Objectives

1) Determine the effects of switchgrass production on SOC sequestration, soil microbial biomass C and N, and soil C and N dynamics compared to other forage grasses and cultivated cropping systems.
2) Utilize the above measurements plus other selected soil properties to estimate effects of switchgrass production on soil quality as compared to other forage grasses and cultivated cropping systems.

CHAPTER II

LITERATURE REVIEW

Improved agricultural practices have great potential to increase the amount of C sequestered in cropland soils. By the adoption of recommended management practices (RMPs), agriculture contributes not only to soil conservation and water quality goals, but also to enhancing the amount of SOC and mitigating CO_2 emission effects on climate change (Follet, 2001). However, public policy makers and politicians are frequently insufficiently aware of this potential. The term “climate change” raises the concerns of some that it is a threat, while others are skeptical that it is real. Climate change refers to long-term alterations in temperature, precipitation, wind and other elements of the earth’s climate system. Natural processes such as solar-irradiance variations, deviation in the earth’s orbital parameters, and volcanic activity can cause fluctuations in climate (IPCC, 1996).

The climatic system is also influenced by the concentration of various atmospheric gases, some of which contribute to the phenomenon of global warming. These are called “greenhouse gases” (GHGs). The GHGs can absorb heat, much as a greenhouse glass does, and restrict absorbed heat from radiating back to outer space. Because of this capacity of GHGs to trap solar heat, climatologists and others are concerned about global temperatures which will increase at a more rapid rate than the world can adjust to. Global warming, including the contributions of GHGs, is important because without global warming, estimates of earth’s temperature would be about 34 ^oC lower (IPCC, 1996). Naturally occurring GHGs include water vapor, CO_2, methane (CH_4), and nitrous oxide (N_2O).

The 1996 report of the International Panel on Climate Change (IPCC) states that there is “clear evidence that human activities have affected concentrations, distributions and life cycles of these gases" (IPCC, 1996). Since about 1750, the concentrations of CO_2, CH_4, and N_2O, have increased 30 (from 270-290 to 370 ppm), 145 (from 0.007 to 1.714 ppm), and 13% (from 0.275 to 0.311 ppm), respectively (Follet, 2001). Agricultural activities contribute CO_2 emissions to the atmosphere from fossil-fuel combustion, farm chemical manufacture, soil erosion processes, and the loss of native SOM. Lal et al. (1998) estimated that CO_2 emissions for US agriculture are about 42.9 million metric tons of C equivalents (MMTEC) per year. Long-term measurements of the increasing concentration of atmospheric CO_2 show that atmospheric CO_2 concentration has increased to 370 ppm during the last half of the 20th century. After remaining near 270-290 ppm during the past several thousand years, this increase was coincident with the rapid rise of fossil-fuel burning during the same period (Sarmiento and Wofsy, 1999). Although there is no consensus as to how much change will occur, there is general agreement that it is worthwhile to reduce GHGs emissions to decrease the risks that many scientists feel are associated with climate change (Follet, 2001).

The role of soils as sinks for atmospheric CO_2 in the global carbon cycle is of considerable importance because ≈ 66% of terrestrial C is below ground and below ground C typically has a longer turnover time than aboveground C (IGBP Terrestrial Carbon Working Group, 1998). It is estimated that globally, terrestrial soils contain ≈ 1580 Gt of C, which is more C than contained in terrestrial vegetation (≈ 610 Gt C) and in the atmosphere (≈ 750 Gt C) (Schimel, 1995). Confidence limits about estimates of the global SOC inventory are unquestionably large, but a small percentage difference in the amount of SOC could have important implications for increasing or decreasing atmospheric CO_2 concentration and global climate change. Lal et al. (1998) proposed that small increases (<0.1%) in SOC storage on abandoned or intensively cultivated lands could help to restore soil quality and alleviate increasing atmospheric CO_2 concentrations that may lead to global warming.

Losses of SOC as a result of conversion of grassland to cropland are well documented (Haas et al., 1957). It has been reported that cultivation results in soil C losses of between ≈20 and 40% over 5 to 20 yr (Mann, 1986). The capacity to sequester soil C by growing switchgrass on lands degraded by long-term cultivation will depend partly on soil type and the initial SOC inventory (Bransby et al., 1998). Garten and Wullschleger (1999) found that there was more coarse root C (i.e., greater root C inventories) under switchgrass than under tall fescue (*Festuca arundinacea* Schreb.), corn (*Zea mays* L.), native pasture, or fallow soils. The amount of root C beneath switchgrass was comparable to that under nearby forest soils. Standing root biomass beneath switchgrass plots averaged between 23.8 and 35.53 mg C cm^{-2}. Roots were the primary source of new C_4-derived SOC beneath switchgrass plots because all aboveground biomass was removed by annual harvest. As a result of this management practice, the contribution of senescent aboveground material to soil was negligible. The annual input of SOC under switchgrass ranged from ≈ 17 to ≈ 21 mg C cm^{-2} yr^{-1} (1,700 to 2,100 kg C ha^{-1}). The latter C input to soils from roots was about one-third of the C captured aboveground by switchgrass annual production. The calculated turnover time for C in coarse switchgrass roots ranged from 1.4 to 2.1 yr. The fraction of new C_4-derived SOC increased with annual temperature indicating a more rapid rate of SOC sequestration beneath switchgrass grown in warmer climates. The turnover time of SOC decreased with decreasing mean annual temperature, indicating slower decomposition rates in cooler climates (Garten and Wullschleger, 2000).

Soil organic matter can be divided into two distinct fractions: i) a large passive pool that is resistant to further decomposition, but provides chemical and physical stability to soils (it is composed mainly of lignin-containing compounds or physically protected C), and ii) a small active pool, including soil microbial biomass (SMB) that is the primary source of mineralizable nutrients. This pool consists of materials having greater water-soluble C (simple sugars, organic acids, and proteins). The quantity and rate of SOM turnover are often altered when natural ecosystems are transformed into more intensively managed production systems. It is generally accepted that SOM contains fractions with a rapid turnover rate (i.e., weeks and months) as well as fractions with a slower turnover rate (i.e., years and centuries) (Schimel et al., 1985). Differences in turnover rates of SOM fractions may be due to physical protection of organic matter within soil aggregates as well as chemical protection from humification (Cambardella and Elliot, 1992). The fractions of SOM that turn over rapidly are believed to make a greater contribution to nutrient cycling than fractions that turn over slowly because they provide a more readily accessible source of energy for soil microorganisms responsible for nutrient cycling (Janzen et al.,1992).

Modification of the soil environment by various crop management strategies or tillage practices can significantly affect soil quality, N cycling, and crop growth through influences on depth distribution of SOM, microbial activity and nutrient mineralization/immobilization (Doran and Smith, 1987). Conventional tillage operations, such as plowing, promote the loss of SOM through crop residue incorporation, disruption of soil aggregates, and increased aeration (Balesdent et al., 1990). Conversely, tillage systems that reduce tillage and increase surface crop residue inhibit loss of SOM. Similar results would be expected in soils under perennial grasses since no tillage is occurring. Collins et al. (1992) demonstrated that soils under permanent vegetative covers, such as grasses, usually have much greater SMB than cultivated soils because of greater organic C input and less physical disturbance. Soil organic C and total N were greater in annual crop than wheat-fallow rotations, exhibiting values of 10.5 and 0.72 g kg^{-1} in the fall-burned wheat-fallow, and 22.2 and 2.00 g kg^{-1} soil in the grass pasture, respectively. Perennial grass cover increased soil C at an average rate of 1.1 Mg C ha^{-1} yr^{-1} to a 3-m depth at selected Conservation Reserve Program (CRP) sites in Texas, Kansas, and Nebraska (Gebhart et al., 1994). Tillage and crop residue incorporation were associated with high soil CO_2-C efflux (Kessavalou et al., 1998). Carbon loss to the atmosphere occurred at flux densities averaging 4.2 to 5.8 kg CO_2-C ha^{-1} d^{-1} during a 60-d period following tillage (Dao, 1998). Significant long-term losses of C and N increased with cultivation and tillage intensity, averaging up to 530 kg C ha^{-1} yr^{-1} (Bowman et al., 1990; Doran et al., 1998). Reduction in tillage and an increase in cropping intensity were needed to slow the decline in soil C (Bowman et al., 1999; Allmaras et al., 2000). Perennial grasses have a high relative allocation of C belowground. Higher C inputs and an absence of tillage disturbance are the principal reasons that perennial grasses sequester C (Paustian et al., 1997). Carpenter-Boggs et al. (2003) found that soils managed under permanent grass contained approximately 160% greater labile C and 50% greater microbial biomass than NT and CT soils. Grassed soils also mineralized 460% greater N under anaerobic conditions and 80% greater under aerobic conditions, while potential nitrification was 25% greater on average than cropped soils. Mycorrhizal fungi colonized 76% of observed root segments under grass, 63% under NT, and 55% under CT. The large difference between grassed soils and cropped soils may be due to the constant presence of vegetation and roots of permanent grass.

Salinas-Garcia et al. (1997) showed that conservation tillage increased SMB C and N and mineralizable C and N compared to more intensive tillage systems. In this experiment, continuous long-term (16 yr) tillage and N fertilization treatments significantly affected the concentration and depth distribution of SOC. Soil organic C, SMBC, and the proportion of SOC present as SMBC in the surface 0 to 50 mm were 39 to 105%, 24 to 160%, and 23 to 63% greater under no-tillage (NT) than under plowed treatments. As expected, mineralizable C and N were consistently higher under NT throughout the growing season than under plowed treatments. Reduction in tillage not only increased SOC and SMBC, but also the proportion of SOC present as SMBC. Similar results are expected in soils under grasses compared to cultivated cropping systems, since tillage normally is not used on soils under perennial grasses. Increasing values of SOC present as SMBC may signal soil quality improvement, since SMBC is a more labile source of mineralizable nutrients. Long-term intensive tillage may not be sustainable, especially in soils with low initial concentrations of SOM (Salinas-Garcia et al., 1997). Franzluebbers et al. (1994b) quantified long-term changes in SOC, SMB C and N, and mineralizable C and N in continuous wheat, continuous wheat-soybean [Glycine max L. (Merr)], and wheat-soybean-sorghum sequences under CT and NT. Soil organic C, SMBC and mineralizable C at a depth of 0-5 cm were 33 to 125% greater under NT than under CT. Increasing cropping intensity increased SOC up to 22%, SMBC up to 31%, and mineralizable C up to 27% under NT. Crop-management-induced changes in soil moisture, soil temperature, crop rooting, and crop residue input can have a large impact on SMB and mineralizable C and N (Ross, 1987), which in turn affect the ability of soil to supply nutrients to plants through SOM turnover (Bonde and Rosswall, 1987).

Interest exists in the use of biological parameters as indicators of soil quality because these parameters respond more rapidly to changes in soil management than SOC (Anderson and Domsch, 1989). Soil microbial biomass and associated activity have been successfully used as predictors of soil C and N dynamics (Franzluebbers et al., 1994a,b; 1995a; Salinas-Garcia et al., 1997), i.e. SMBC was a good predictor of C and N mineralization in a 24-day incubation period. Soil microbial biomass is more sensitive to subtle changes in soil quality than SOC and, therefore, should be a better estimator of the effects of crop and management strategies on soil C and N dynamics and sustainability. Soil organic C changes slowly and differences are often difficult to quantify because of the large background and intrinsic spatial variability of SOC already present. Measurement of the living fraction of SOM, the SMBC, for relatively short periods has identified early changes in SOM that modify nutrient dynamics long before these can be detected by chemical analysis (Powlson et al., 1987).

Seasonal changes in soil moisture, soil temperature, and C input from crop roots (i.e. root exudates, mucilage, sloughed cells, etc.) and crop residues can have a large effect on SMB and its activity (Ross, 1987). In an experiment by Franzluebbers et al. (1994b), SMBC increased significantly from planting to flowering in all crop sequence and tillage regimes. At harvest, SMBC had returned to the amount at planting for intensive crop sequences, continuous wheat-soybean and rotated wheat-soybean-sorghum. This seasonal pattern of SMBC is probably a result of increased C input from rhizosphere products to the soil before and during flowering, especially during fluctuating spring temperatures. In continous wheat, however, SMBC was greater at harvest compared to planting. The fallow period before planting of wheat was 6 months, while the fallow period for the intensive crop sequences was 3 and 1 month, respectively. A longer period of decomposition without C input in continuous wheat probably contributed to the lower amount of SMBC at planting compared to harvest than in more intensive crop sequences. Soil microbial biomass N did not increase significantly from planting to flowering as was observed for SMBC. This resulted in greater C-to-N ratios of SMB during flowering and at harvest compared to planting. Average C-to-N ratios of SMB were 11.1 at planting, 12.8 during flowering and 13.4 at harvest. Greater C-to-N ratios of SMB at flowering and harvest coincided with greater addition of organic C substrates (i.e. rhizosphere products, crop roots, and crop residues).

Nitrogen is the nutrient most commonly limiting crop production worldwide and the fertilizer nutrient applied in the greatest amounts. Efficiency of N use by plants is governed by soil characteristics (pH, CEC, organic matter, texture, type of clay, aeration and compaction), climatic factors (temperature, precipitation amount and timing, evaporation and growing period), agronomic practices (tillage, seeding, crop rotation and pest management), crop type and the management of fertilizer applications (Malhi et al., 2001). Nitrogen in soils is subject to volatilization, immobilization, denitrification and leaching. Overall efficiency of applied N is generally <50% in the tropics (Baligar and Bennett, 1986) and <70% in temperate regions (Malhi and Nyborg, 1991), clearly indicating that our understanding of optimal fertilizer management in various ecosystems is still incomplete. Producers are increasingly adopting reduced tillage systems to improve water use efficiency, increase cropping intensity and diversity, improve the economics of crop production and reduce the risk of soil erosion and degradation (Lafond et al., 1992).

Nitrogen is a key element in plant nutrition that limits production when the inorganic supply in soil is low and that may become a contaminant when NO_3^- is excessive (Franzluebbers et al., 1995c). Soil microorganisms play an integral role in N cycling as both the transformation agent and source/sink of N (Duxbury et al., 1991). Biological cycling of N in soil is strongly linked to the dynamics of C. Soil N mineralization is a ubiquitous biogeochemical transformation that occurs as microorganisms metabolize C in SOM, with inorganic N being released as a consequence. The rate of N mineralization is therefore intimately related to C mineralization. Mineralization is influenced by soil biological, chemical, and physical properties, crop residue composition, climate, and management factors (Franzluebbers et al., 1994a,b; 1995a,b,c). Nitrogen is immobilized into the SMB and subsequently mineralized as a result of SMB turnover. Abundant, easily decomposable organic substrates that have low N concentration often lead to temporary N immobilization (Mary et al., 1993). When organic substrates limit microbial growth, N that was incorporated into the increasing SMB becomes mineralized. The size and activity of SMB are regulated by environmental factors (e.g. temperature and moisture) and substrate quality. Seasonal changes in environmental factors and substrate quality, therefore, are important in determining mineralization and immobilization of N. Potentially mineralizable N has been shown to vary from one season to the next (Bonde and Rosswall, 1987), reflecting the dependence of mineralized N and its agent of transformation, the SMB, on seasonal organic inputs from crop roots and residues (Franzluebbers et al., 1994b, 1995b). Organic inputs from rhizodeposition and crop roots and residues are seasonally and spatially (i.e., placement with tillage) dependent. Tillage regimes differing in crop residue placement and soil disturbance may alter the short-term rate of changes occurring in the active soil C and N pools, thereby altering long-term levels of these properties. In addition, crop species can alter the quantity and quality (i.e., N concentration) of organic inputs (Franzluebbers et al., 1995c).

Nitrogen mineralization is an important indicator of soil quality (Duxbury and Nkambule, 1994; Seybold et al., 1998), and its management could represent an excellent tool for achieving a sustainable N supply. Better management of N mineralization is likely to result in more synchronized N release, and has the potential to reduce N fertilizer dependence, while promoting N recycling within agroecosystem boundaries. Nitrogen mineralization is a microbiologically-mediated process (Paul and Voroney, 1984), and the microbial biomass is largely controlled by organic C content and by recent substrate additions (Paul and Clark, 1996). Microorganisms are the main mediators of C turnover in soil. By definition they also are part of the organic C and nutrient pool (Insam et al., 1989). The quality of a particular material is defined by its chemical composition, including C/N ratio, lignin, and polyphenol contents (Tian et al., 1997). Substrates with low N and high concentrations of lignin and polyphenols decompose and release N slowly (Cornforth and Davis, 1968). In contrast, those rich in N with low lignin and polyphenol concentrations decompose rapidly (Hadayanto et al., 1997). For instance, legumes with narrow C/N ratios and abundant and soluble compounds are more likely to mineralize at higher rates than residues from grasses with high C/N ratios. With changes in the quantity and quality (e.g. N concentration) of SOM and SMB pools, the potential of soil to supply and sequester nutrients, especially N, is altered through changes in mineralization-immobilization turnover (Jansson and Persson, 1982). Franzluebbers et al. (1994b) showed that mineralizable N was highly correlated with SOC, total soil N, SMBC, SMBN, and mineralizable C. Mineralized N was an average of 45% greater under NT than under conventional tillage (CT). This result suggests that perhaps a greater quantity of active N resided in soils under NT, and may be directly linked to the conservation of active and passive SOM pools under NT. Greater N uptake under rotated than continuous sorghum under NT may be partly explained by differences in N supplied through mineralization from coarse organic residue N. Averaged across crop management systems, coarse organic residue N declined from post-harvest (1.8 g m^{-2}) to planting (1.4 g m^{-2}) to flowering (1.1 g m^{-2}). Mineralization of N from the coarse organic residue pool may have contributed to the net N mineralization under field conditions, especially under NT, which generally had a larger coarse organic residue N pool than CT.

Net N mineralization in soils can be derived from steady state turnover of SOM, decreases in SMB at certain times of the year (Salinas-Garcia et al., 1997), and decomposition of added crop residues. Nonsynchronous N mineralization and crop growth can result in lower yield and greater potential for N pollution. Inorganic and active organic soil N pools are essential for plant nutrition, but can threaten water quality when excessive. To meet the goals of profitability and environmental protection, a delicate balance in the inorganic soil N supply must be managed with knowledge of seasonal changes in N dynamics as affected by the timing, quantity, and quality of crop residue production (Paul and Juma, 1981). Nitrogen enrichment of forests by air pollution has become one of the major topics of forest research in recent years. Envisioned ecological consequences of N saturation are ground-water pollution by nitrate and feedbacks on the greenhouse effect due to nitrous oxide emissions from soil. Zechmeister-Boltenstern et al. (2001) found that nitrous oxide emissions in a beech forest with undergrowth of *Allium ursinum* resulted in 3.6, 4.2, and 4.3 kg N_2O-N ha^{-1} in 1996, 1997, and 1998 respectively. The values found are within the upper range of values reported for temperate upland forest soils (Papen and

Butterbach-Bahl, 1999). These authors also found that nitrate leaching occurred at times of high precipitation, with the first leaching event occurring when *Allium* plants lost their flowers and were wilting. Substantial nitrate movement was also observed one month after the complete decline of *Allium*, and this was accompanied by a significant decline of nitrogen stored in the microbial biomass. Calculated nitrate leaching rates ranged from13 to 31 kg N ha^{-1}. Plant residues play an essential role in the cycling of nutrients in agricultural ecosystems. The quantity and quality of residues and the tillage system used for their introduction into soil are factors that affect the fate of C and nutrients. The ratio between available C and N is an important factor determining whether N mineralization or N immobilization will dominate during decomposition of plant residues. Maximizing N delivery to plants and minimizing NO_3^- leaching may be conflicting objectives, and optimal management depends on an understanding of the dynamics of N transformations in the soil.

Plant biomass management practices must not only be assessed agronomically and economically, but ecologically as related to natural resource preservation and environmental pollution (National Research Council, 1989). Greater knowledge of the short- and long-term effects of biomass bioenergy production practices on soil biological and chemical properties is needed to determine the effects of those practices on sustainable land management.

CHAPTER III

MATERIALS AND METHODS

Locations

Switchgrass research plots were established during 1992 and 1997 in Texas and other states in conjunction with DOE-sponsored research. Many of these sites have been continuously maintained in switchgrass for seven or more years. Treatments in this study included switchgrass, other forage grasses, cultivated cropping systems, and forest, though not all at any given location (Table 1).

Table1. Cropping systems sampled at different locations in 1999

Location	Description	Soil Series
Clinton, LA	Alamo switchgrass plots established in 1997. Caddo switchgrass plots established in 1997. Adjacent long-term bahiagrass (*Paspalum notatum* Flugge.) pasture. Adjacent long-term forested area.	Providence Sandy Loam.
Hope, AR	Alamo switchgrass plots established in 1997. Caddo switchgrass plots established in 1997. Adjacent long-term bahiagrass/fescue (*Festuca arundinacea* Scherb.)pasture. Adjacent long-term forested area.	Bowie Fine Sandy Loam.
Dallas, TX	Alamo switchgrass planted in 1992. Alamo switchgrass planted in 1997. Adjacent Coastal bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture with cattle grazing.	Houston Black Clay.

Table 1. (Continued)

Location	Description	Soil Series
	Adjacent cultivated field with cotton (*Gossypium hirsutum* L.)/wheat (*Triticum aestivum* L.) rotation.	
College Station, TX	Alamo switchgrass planted in 1992. Alamo switchgrass planted in 1997. Kleingrass (*Paspalum notatum* L.) planted in 1992. Adjacent sorghum [*Sorghum bicolor* (L.) Moench.]-wheat-soybean [*Glycine max* (L.) Merr] rotation.	Weswood Silt Loam.
Stephenville, TX	Alamo switchgrass planted in 1992. Alamo switchgrass planted in 1997. Coastal bermudagrass plot receiving dairy manure. Nearby cultivated area with wheat/peanut (*Arachis hypagaea* L.) rotation. Cattle grazing of wheat.	Windthorst Fine Sandy Loam.
Yoakum, TX	Oat (*Avena sativa* L.)/peanut rotation. Coastal bermudagrass plus poultry litter. Alamo switchgrass planted in 1997 without N fertilizer. Alamo switchgrass planted in 1997 plus 240 lbs acre^{-1} N.	Strabor Fine Sandy Loam.

Texas sites include College Station, Dallas, Yoakum, and Stephenville; out-of-state sites include Hope, Arkansas and Clinton, Louisiana. Soil sampling occurred during 1999 in early spring (February/March), and fall (December) in the previously described established plots. During December, soil samples from Yoakum were not obtained because of poor stand establishment. Occasionally sampling times had to be altered to better match climate and weather conditions at out-of-state sites. Approximately 15 samples (19-mm dia.) were collected and composited per plot at each sampling. Sampling depths at all locations were 0 to 5, 5 to 15, and 15 to 30 cm. After collection, samples were placed in heavy-duty plastic zip-lock bags and refrigerated at 4 ^{o}C until analysis.

Soil Chemical Analyses

Dried soil (55 ^{o}C) was passed through a 2-mm screen and analyzed for initial NH_4^+-N and NO_3^--N (inorganic) concentrations following extraction with 2*M* KCl. Seven grams of soil were extracted with 28 ml of 2*M* KCl (1:4 w/v) and analyzed using autoanalyzer techniques (Technicon Industrial Systems, 1977a,b). A small portion of the dried soil was further ground to pass a 0.5-mm screen and analyzed for soil organic C by the modified Mebius method (Nelson and Sommers, 1982). Soil total N was determined following acid/salt catalyst digestion (Bremmer and Mulvaney, 1982).

Soil Biological Analyses

Soil microbial biomass C and N, or pool sizes, were determined using the chloroform fumigation-incubation method (Jenkinson and Powlson, 1976) with soils wetted to approximately 0.55 water-filled pore space. Soils were wetted and pre-incubated for 7 days at 25^{o}C prior to fumigation. The flush of CO_2-C released from fumigated samples during a 10-day incubation at 25^{o}C was adjusted with an efficiency factor of 0.41 to estimate SMBC (Voroney and Paul, 1984). Following fumigation-incubation, the soil was dried at 55 ^{o}C for 24 hours, ground to pass a 2-mm screen, and extracted with 2*M* KCl as described previously. Soil extracts were analyzed for NH_4^+-N concentration. Corresponding samples pre-incubated for 7 days at 25^{o}C, then dried and ground were also extracted for NH_4^+-N. Ammonium-N from non-fumigated samples receiving the 7-day pre-incubation was subtracted from that after fumigation and then subsequently adjusted by an efficiency factor of 0.41 to estimate SMBN (Carter and Rennie, 1982).

Soil C and N mineralization were determined from four, 40 to 50-g subsamples wetted to approximately 0.55 water-filled pore space and placed in a 1-L glass jar along with a vial containing 10 ml of 0.5M KOH to trap evolved CO_2 and a vial containing 10 ml of water to maintain humidity. The soils were incubated at 25 ^oC for 24 days. Carbon dioxide-C was determined by titration with standardized 1*M* HCl at 1, 7, 17, and 24 days, replacing the alkali trap each time (Anderson, 1982). Basal soil respiration (BSR) represents the steady state activity of the soil microbial biomass and was measured as the soil C mineralized between 7 and 17 days of laboratory incubation under standard conditions. The inorganic N (NH_4^+-N + NO_3^--N) content of the above soils at 0, 7, 17, and 24 days of incubation was determined following oven drying at 55 ^oC for 24 hours, passing through a 2-mm screen, and extracting with 2*M* KCl as previously described. Total N mineralized was calculated by subtracting initial inorganic N from N mineralized during 24 days of incubation.

Statistical Analyses

Analysis of variance for a three-way (vegetative treatment, depth, and season) factorial was performed. Preliminary analysis showed significant *season x vegetative treatment x depth* interaction. Therefore, analysis of variance was performed separately each season. Analysis of variance of data was accomplished using the JMP statistical package version 4.0.4 (SAS Institute Inc., 2001). Main and interactive effects were compared using Tukey's procedure for pairwise comparison of means at a 0.05 level of significance (Steel and Torrie, 1980). Regression functions were utilized to compare cumulative C and N mineralization with microbial biomass C and N over time.

CHAPTER IV

RESULTS AND DISCUSSION

March Sampling

Soil Organic Carbon

Soil organic C varied with cropping system, location, depth, and season. During March sampling, SOC averaged across depth at Clinton was greatest under bahiagrass (12 g kg^{-1}) and the forested area (11 g kg^{-1}), and lowest under Alamo (9 g kg^{-1}) and Caddo switchgrass (9 g kg^{-1}) (Fig. 1a). Franzluebbers et al. (2000) found that SOC and N at a depth of 0-20 cm were greater under grass-based management systems compared with forest or cropland. At this location, bahiagrass had the highest value of SOC, but was not significantly different than the forested area. Bahiagrass pasture and forest were significantly greater than both switchgrass treatments, and had 33 and 22% more SOC than the switchgrass treatments, respectively. The low SOC value under switchgrass treatments at this location was probably due to their recent establishment and should increase with time. Franzluebbers et al. (2000) also found that particulate organic C and N increased with stand age under both tall fescue and bermudagrass. It is also expected that SOC will increase with stand age under switchgrass treatments.

At Hope, AR, SOC concentrations were not significantly different among the four treatments at 0-5 cm, but at 5-15 cm, Alamo (9 g kg^{-1}), bahiagrass/fescue (8 g kg^{-1}), and Caddo (8 g kg^{-1}) had significantly greater SOC than the forested area (5 g kg^{-1}). Alamo and Caddo switchgrass had 80 and 60% more SOC than the forested area at this depth, respectively. The treatments were not different at the 15-30-cm depth. (Fig. 2a).

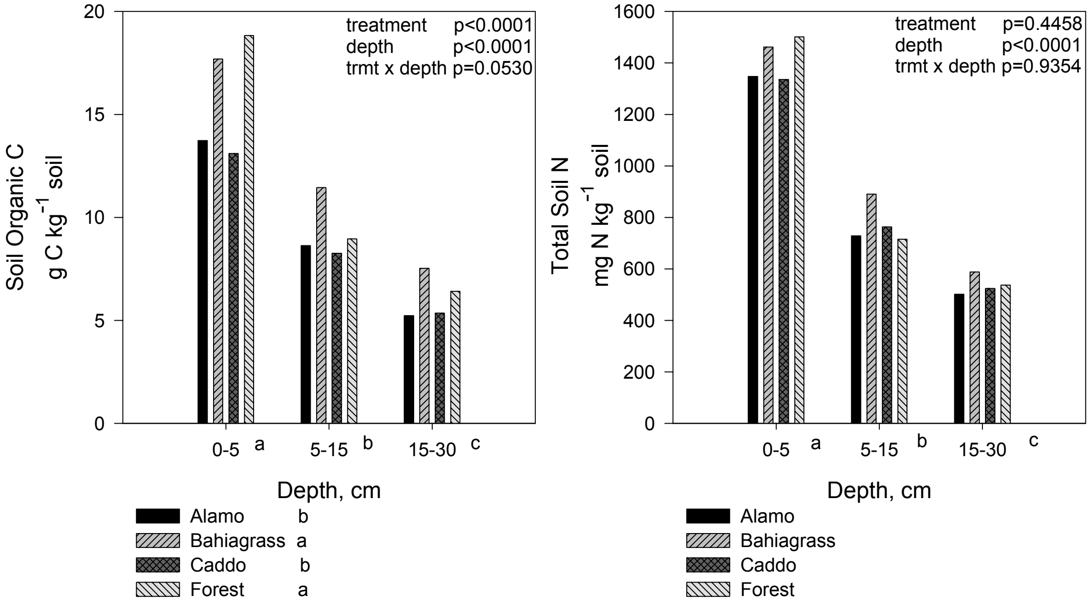
Figure 1a

Figure 1b

Figure 1. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Clinton, LA, March 1999.

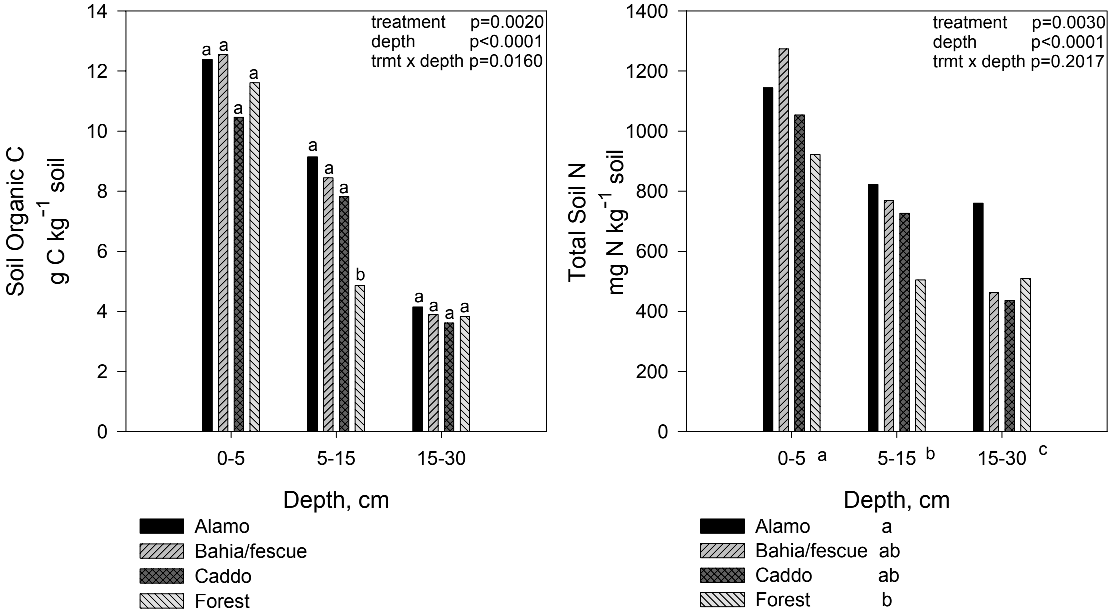
Figure 2a.

Figure 2b.

Figure 2. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Hope, AR, March 1999.

There was insufficient information from this study to determine whether SOC under forest was different than under grass vegetation. Soil organic C under a forested area was not significantly different than under switchgrass in an experiment by Corre et al. (1999). When comparisons were made by pooling the data from all locations, significant differences among vegetation types were not detected. The authors suggested that the inconsistent nature of differences between forest and grasses could be attributed in part to their ages. Soil organic C was highest under forest at three locations (where forest age was >60 y), and was highest under grass at two locations (where forest age was only ≈ 30 y).

Greatest values of SOC were observed in samples from Dallas (approximately twice that of other locations), primarily because of the high monmorillonitic clay content of Houston Black Clay (Fig. 3a). At this location, samples from 0-5 cm under long-term Coastal bermudagrass pasture showed the greatest SOC (30 g kg^{-1}), followed by Alamo switchgrass planted in 1992 (27 g kg^{-1}), and 1997 (25 g kg^{-1}), and was lowest under the wheat-cotton rotation (18 g kg^{-1}). At the 5-15 and 15-30-cm depths, SOC in bermudagrass and switchgrass treatments was not different, but it was greater than that in the wheat cotton rotation, which showed the lowest values of SOC at all three depths. The bermudagrass treatment is a long-term grazed pasture (>40 years), which may help explain the high values of SOC under this treatment. Franzluebbers et al. (2000) found that SOC and N at a depth of 0-20 cm were greater under grass-based management systems compared with forest or cropland. The authors also found that SOC and particulate organic C and N were greater under grazed than under hayed bermudagrass. Grazing of pastures appears to be beneficial to storage of soil C and N pools by recycling undigested forage in the pasture via excreta. More than two thirds of ingested nutrients are returned to the pasture via excreta (Till and Kennedy, 1981).

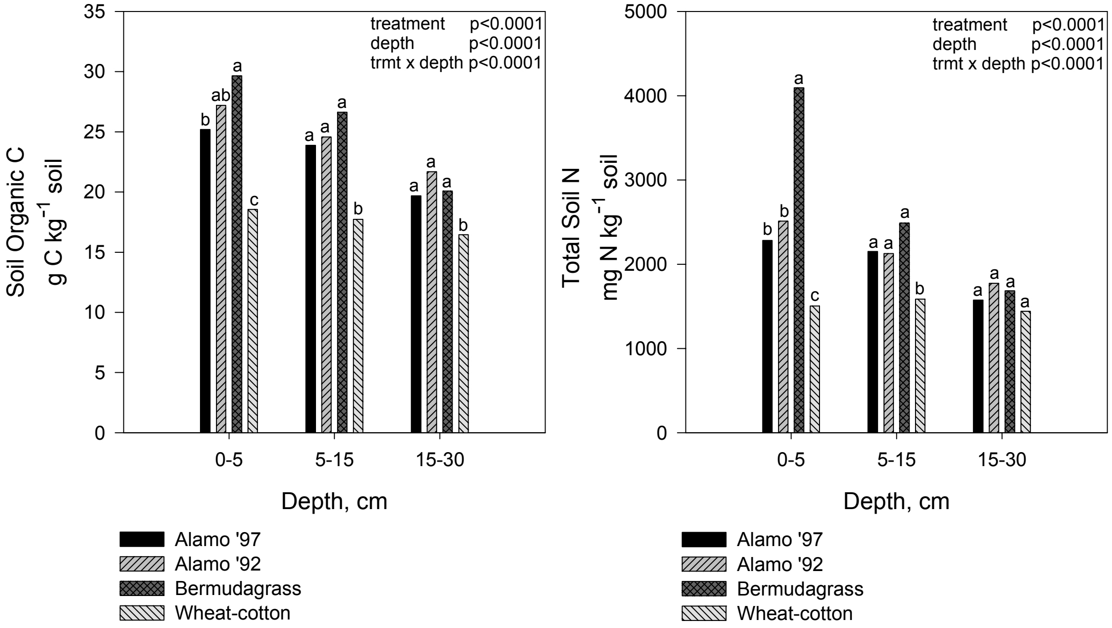

Figure 3a.

Figure 3b.

Figure 3. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Dallas, TX, March 1999.

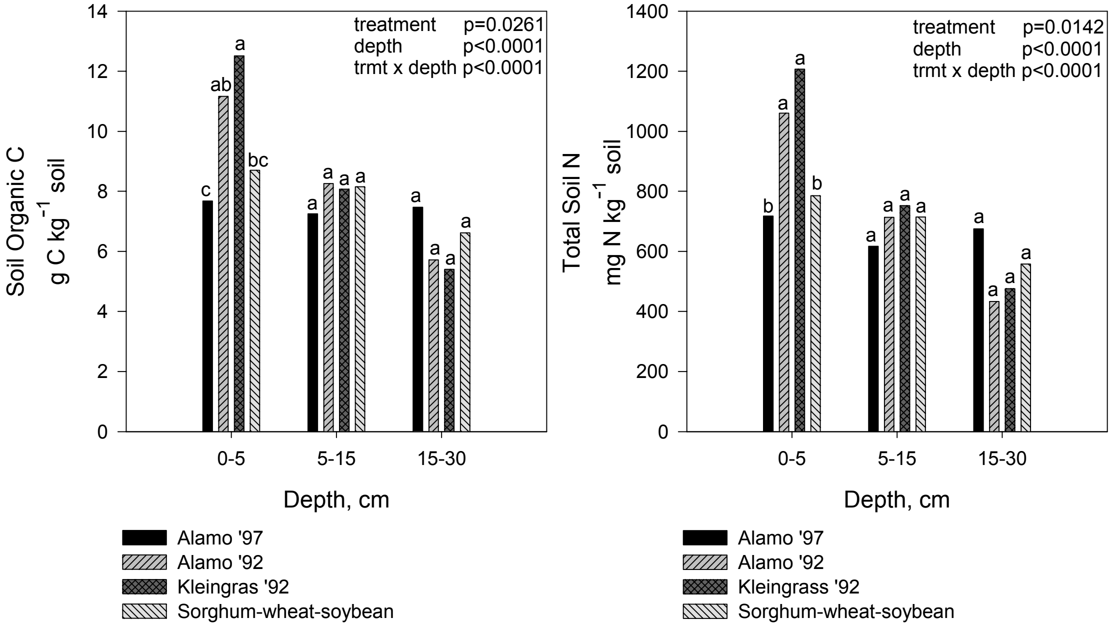

Figure 4a.

Figure 4b.

Figure 4. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. College Station, TX, March 1999.

Hay harvest removes nutrients and reduces the amount of decomposable substrates added to the soil, which affect C and N pools and processes. Similarly in this study, the biomass of switchgrass is harvested for potential use as biofuel. Soils under Alamo switchgrass planted in 1992 and 1997 had 42 and 32% more SOC, respectively, than that under the wheat-cotton treatment at 0-5-cm depth, 39 and 33% more at 5-15 cm, and 38 and 25% more at 15-30 cm-depth respectively, suggesting a greater potential to sequester C compared to cultivated soils. Loss of SOC as a result of soil cultivation has been well documented (Hass et al., 1957; Mann, 1986; Franzluebbers et al., 1998).

At College Station, SOC at 0-5-cm was greatest under kleingrass planted in 1992 (13 g kg^{-1}) and Alamo switchgrass planted in 1992 (11 g kg^{-1}), followed by the sorghum-wheat-soybean rotation (9 g kg^{-1}) and Alamo planted in 1997 (8 g kg^{-1}). Treatments were not different at 5-15- and 15-30-cm depths (Fig. 4a). At this location, although the tillage rotation study was cultivated, two high residue crops, grain sorghum and wheat, are used. This fact may help explain why SOC in the cultivated tillage rotation treatment was not significantly different from Alamo planted in 1992, contrary to the findings at Dallas and Stephenville where SOC under Alamo planted in 1992 was significantly higher than in cultivated treatments. Franzluebbers et al. (1998) found that SOC to a depth of 20 cm increased with cropping intensity as a result of greater C input and was 10 to 30% greater under no tillage (NT) than under conventional tillage (CT). Total C input (above- and below-ground) increased 42 to 46 g m^{-2} yr^{-1} for each additional month of cropping under both tillage regimes. Higher intensity cropping systems made better use of resources by producing biomass throughout the year. Higher intensity systems may increase risk of a particular crop failure, but with extended time will likely capture more opportunities for greater potential return than single-crop systems.

Soil organic C at Stephenville in the 0-5-cm depth was greatest under bermudagrass (14 g kg^{-1}), followed by Alamo planted in 1992 (11 g kg^{-1}), and lowest under Alamo planted in 1997 (6 g kg^{-1}) and the wheat-peanut rotation (5 g kg^{-1}) (Fig. 5a). At 5-15- and 15-30-cm depths, differences were not as pronounced, although bermudagrass and Alamo planted in 1992 resulted in the greatest SOC values. As in Dallas, the bermudagrass at this location is a long-term pasture that has received cattle manure, which may help explain the high values compared to the other treatments. Alamo planted in 1992 had more than twice the amount of SOC than the wheat-peanut treatment, indicating that cultivation may be especially detrimental to SOC in this soil.

Soil organic C at Yoakum in the 0-5-cm depth was greatest under bermudagrass + poultry litter (8 g kg^{-1}), followed by the oat-peanut rotation (5 g kg^{-1}), and was lowest under Alamo without N fertilization (3 g kg^{-1}), and Alamo + 292 kg N ha^{-1} (2 g kg^{-1}) (Fig. 6a). Low SOC values from switchgrass at this location are probably due to very recent establishment and should increase with time. At Yoakum, all Alamo switchgrass plots were established in 1997. A significant effect of N fertilization on SOC was not observed. Muir et al. (2001) found that biomass production of switchgrass increased linearly with increasing N rate, but that first year production was likely restricted from plants that had not developed deep root systems. As a result, the stand may not have been fully capable of responding to applied fertility. A similar effect may have occurred at the Yoakum location.

Total Nitrogen

Total N generally followed similar trends as those of SOC. At Clinton, soil total N concentrations under the different vegetational treatments were not significantly different, averaging 908 mg N kg^{-1} soil (Fig. 1b).

Total N at Hope was greatest under Alamo (909 mg kg^{-1}), and second highest under bahiagrass (835 mg kg^{-1}), followed by Caddo (733 mg kg^{-1}), and

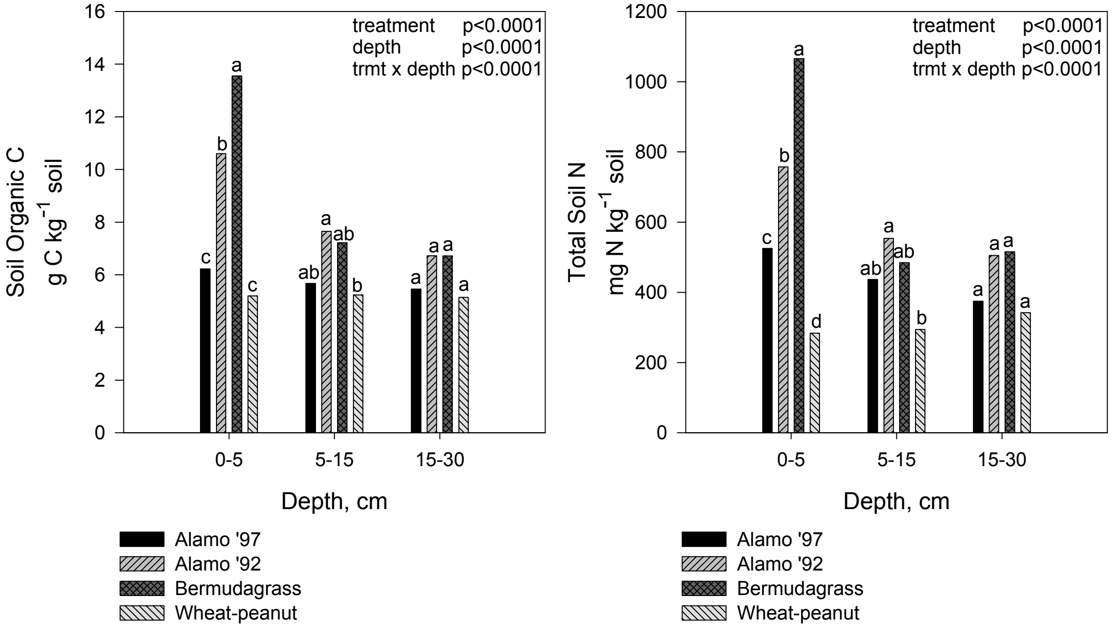

Figure 5a.

Figure 5b.

Figure 5. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Stephenville, TX, March 1999.

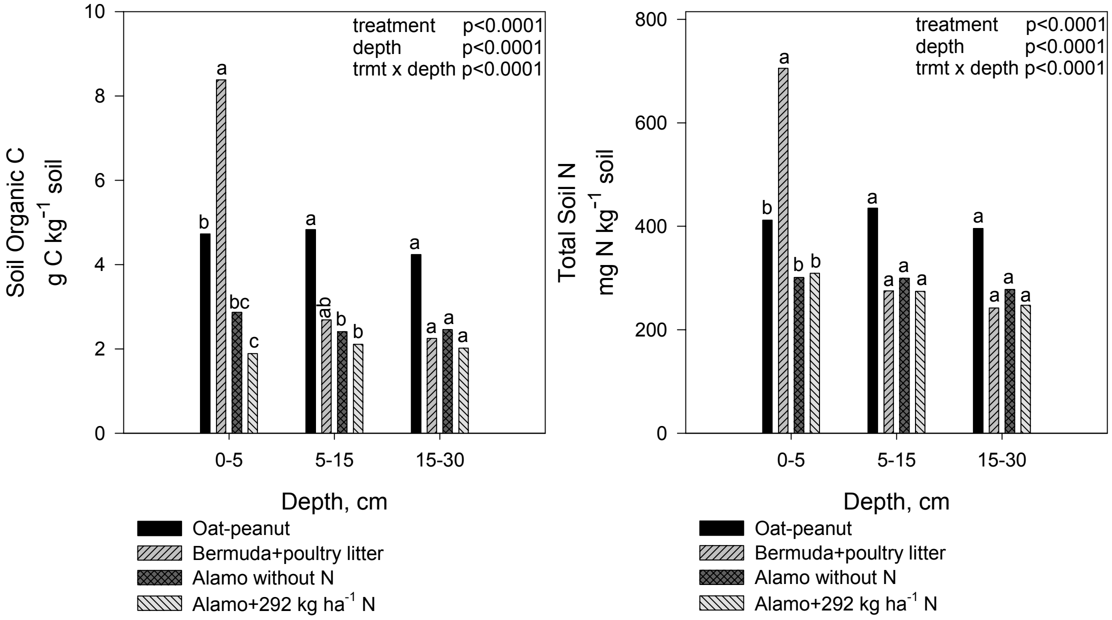

Figure 6a.

Figure 6b.

Figure 6. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Yoakum, TX, March 1999.

lowest under the forested area (645 mg kg^{-1}) (Fig. 2b). Franzluebbers et al. (2000) found that forestland contained less total N than grass-based management systems, even though forestland had a significantly greater standing stock of SOC (when the sum of surface residue and SOC was considered).

Soil total N at 0-5 cm at Dallas was greatest under bermudagrass (4093 mg kg^{-1}), followed by Alamo planted in 1992 (2512 mg kg^{-1}) and in 1997 (2282 mg kg^{-1}), and lowest under the wheat-cotton rotation (1504 mg kg^{-1}) (Fig. 3b). Bermudagrass and switchgrass treatments were not different at 5-15 cm, but the wheat-cotton rotation was significantly lower than the rest of the treatments. As expected, bermudagrass showed the highest value since it is a long-term grazed pasture, and grazing appears to be beneficial to soil C and N storage by recycling undigested forage in the pasture via excreta (Franzluebbers et al., 2000). Alamo switchgrass planted in 1992 and 1997 had 67 and 52% more soil total N than the cultivated wheat-cotton rotation treatment. Previous studies have found that soil organic N was greater under NT (similar to permanent vegetative covers) than under CT (Franzluebbers et al., 1999), and also that particulate organic N was greater under bermudagrass pasture than under NT (Franzluebbers et al., 2000). Therefore, it was expected that switchgrass treatments would have greater total N than cultivated soils.

At College Station, soil total N at 0-5 cm was greatest under kleingrass (1207 mg kg^{-1}) and Alamo planted in 1992 (1060 mg kg^{-1}), and lowest under the sorghum-wheat-soybean rotation (786 mg kg^{-1}) and Alamo planted in 1997 (718 mg kg^{-1}) (Fig. 4b). No significant treatment effects on soil total N were observed at deeper depth at this location. Soil total N followed similar trends as those of SOC, where values for the sorghum-wheat-soybean rotation were not significantly different than those for Alamo planted in 1997, probably because of the two high residue crops used in the rotation, grain sorghum and wheat. The rotation also includes soybean, a legume that could increase the N content in the soil by symbiotic N_2-fixation.

At Stephenville, soil total N at 0-5 cm was greatest under bermudagrass (1065 mg kg^{-1}), and second highest under Alamo planted in 1992 (757 mg kg^{-1}), followed by Alamo planted in 1997 (525 mg kg^{-1}), and lowest under the wheat-peanut rotation (284 mg kg^{-1}) (Fig. 5b). The highest value under bermudagrass was likely due to the fact that it is a pasture that receives an annual application of 400 kg N ha^{-1} as dairy manure. Alamo planted in 1992 had 2.7 times more total N, and Alamo planted in 1997 had 84% more total N than the wheat-peanut cultivated treatment. Franzluebbers et al. (1994b) found results suggesting conservation of active and passive SOM pools under NT (similar to permanent vegetative covers) compared to CT.

At Yoakum, soil total N at 0-5 cm followed a similar trend as that of SOC, being greatest under bermudagrass + poultry litter (705 mg kg^{-1}), and lower under the oat-peanut rotation (412 mg kg^{-1}), Alamo + 292 kg N ha^{-1} (309 mg kg^{-1}), and Alamo without N fertilization (301 mg kg^{-1}) (Fig. 6b). The low values under switchgrass may be due to its recent establishment and should increase with time.

Soil Microbial Biomass Carbon

Soil microbial biomass C (SMBC) is the most active fraction of SOC and is responsible for nutrient cycling/turnover in soils. Results from College Station demonstrated the close association expected between SMBC and soil microbial biomass N (SMBN) (Fig. 7). Trends in SMBC were generally the same as those of SOC, and also decreased with depth.

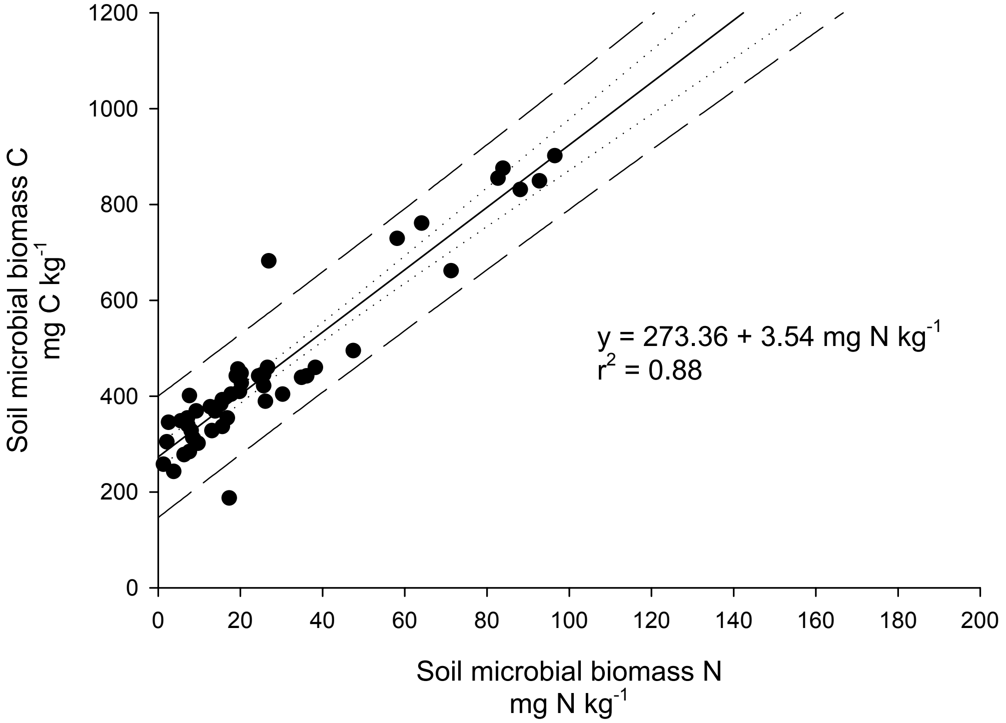

Figure 7. Regression of soil microbial biomass C vs. soil microbial biomass N. College Station, TX, March 1999.

Soil microbial biomass C at Clinton was greatest under bahiagrass (515 mg kg^{-1}), followed by Caddo (432 mg kg^{-1}) and Alamo switchgrass (418 mg kg^{-1}), and the forested area (386 mg kg^{-1}) (Fig. 8a). Values of SMBC in the two switchgrass treatments and the forested area were not different. The long-term bahiagrass pasture also had the greatest SOC concentration (Fig. 1a). The forest soil also showed a relatively high value of SOC, but the lowest value for SMBC, possibly indicating the recalcitrant nature of the organic matter or soil conditions not conducive to microbial growth. Results for switchgrass

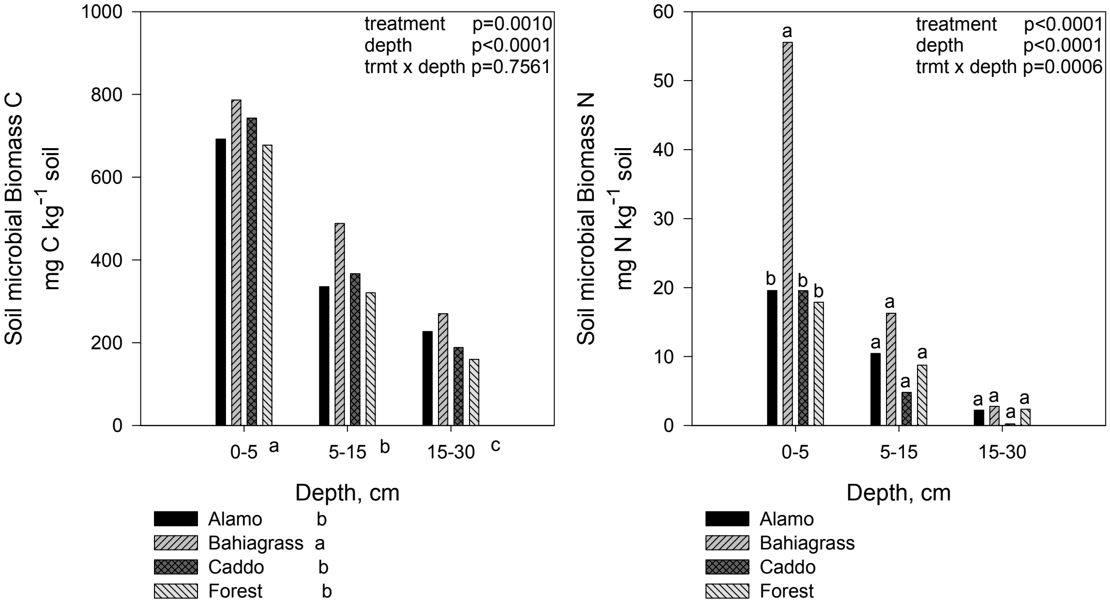
Figure 8a.

Figure 8b.

Figure 8. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Clinton, LA, March 1999.

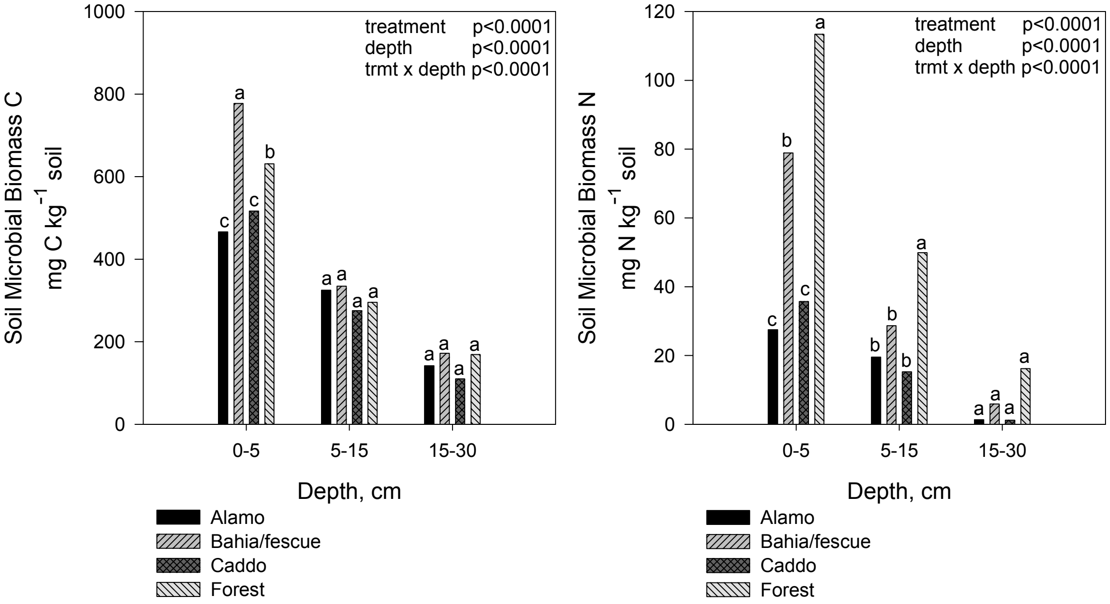
Figure 9a.

Figure 9b.

Figure 9. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Hope, AR, March 1999.

treatments and the forested area were not significantly different, even though the switchgrass treatments were recently established. These results suggest that switchgrass residues or its root biomass (switchgrass has an extensive root system) may be a better or more readily useable substrate for sustaining microbial populations. Corre et al. (1999) found that neither forest nor C_3 or C_4 grasses consistently supported the highest amounts of water-extractable organic C (WEOC), bioavailable dissolved organic C (BDOC), and the proportion of BDOC to WEOC (%BDOC) across locations. Water-extractable organic C is likely the most labile and mobile form of SOC (Qualls and Haines, 1992; DeLuca and Keeney, 1993; Nelson et al., 1994). Recent research (Cook and Allan, 1992; Boyer and Groffman, 1996; Jandl and Sollins, 1997) used BDOC as a measure of how much WEOC is readily available to microbes. Earlier studies showed that differences in BDOC between forest and corn (Boyer and Groffman, 1996) and between forest soils with or without forest litter (Jandl and Sollins, 1997) were related to the inherent ‘litter quality’ of the vegetation. Corre et al. (1999) found that soils under switchgrass had about the same or greater content of BDOC than forest soils.

Soil microbial biomass C at Hope in 0-5 cm was greatest under bahiagrass (765 mg kg^{-1}), followed by forest (631 mg kg^{-1}), and was lowest under Caddo (517 mg kg^{-1}) and Alamo switchgrass (484 mg kg^{-1}) (Fig. 9a). Recent establishment of switchgrass may explain the low values of SMBC compared to the other treatments. Results at this location are different from those at Clinton, possibly because of differences in tree species and age of forest (Corre et al., 1999). Previous study by Franzluebbers et al. (2000) found that SOC and SMBC were greatest under bermudagrass following forest than following cropland. Hu et al. (1997) also found that SMBC was greater under forest than under NT, CT, and fescue sods. Ellert and Gregorich (1995) found equivalent SMBC in grassland and forest at one site, and less SMBC in grassland than forest at another site

Soil microbial biomass C at Dallas at 0-5 cm was greatest under bermudagrass (2167 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (1224 mg kg^{-1}) and 1997 (1132 mg kg^{-1}), and was lowest under the wheat-cotton rotation (809 mg kg^{-1}) (Fig. 10a). Similar differences were evident at 5-15 and 15-30 cm. Franzluebbers et al. (1998) found that SMBC and potential C mineralization were 24 and 63% greater under NT than CT. The authors also found that SMBC and potential C mineralization under CT were 40 to 60% and 33 to 78% of those under long-term pasture. In my study, soil under bermudagrass had 2.6 times more SMBC than under the cultivated soil, and soils under Alamo planted in 1992 and 1997 had 51 and 40% more SMBC than under the cultivated soil. Hu et al. (1997) found that long-term CT also reduced SMBC. The results in my study showed that the cultivated treatment had lower SMBC than treatments where no soil disruption occurred, suggesting cultivation may be detrimental to soil quality and sustainability. Salinas-García et al. (1997) found that conservation tillage systems (similar to permanent vegetative covers) increased SMBC, SMBN, and mineralizable C and N compared to more intensive tillage systems.

Soil microbial biomass C at College Station at 0-5 cm was greatest under kleingrass (859 mg kg^{-1}) and Alamo switchgrass planted in 1992 (757 mg kg^{-1}), and lowest under the sorghum-wheat-soybean rotation (459 mg kg^{-1}) and Alamo planted in 1997 (362 mg kg^{-1}) (Fig. 11a). Alamo planted in 1992 had 65% more SMBC than the sorghum-wheat-soybean rotation. Contrary to the findings at Dallas and Stephenville where Alamo planted in 1992 and 1997 both had significantly greater SMBC than the cultivated soil, at College Station the cultivated soil was not significantly different than under Alamo planted in 1997. Again, this result might be attributed to the more intensive cultivated cropping system at College Station than that at Dallas and Stephenville.

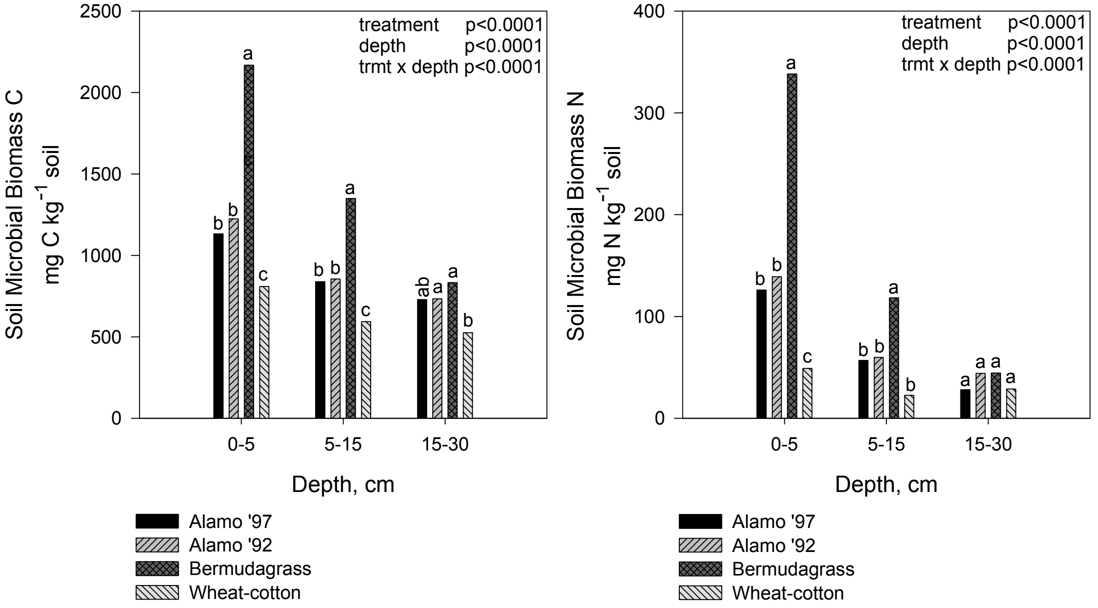
Figure 10a.

Figure 10b.

Figure 10. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Dallas, TX, March 1999.

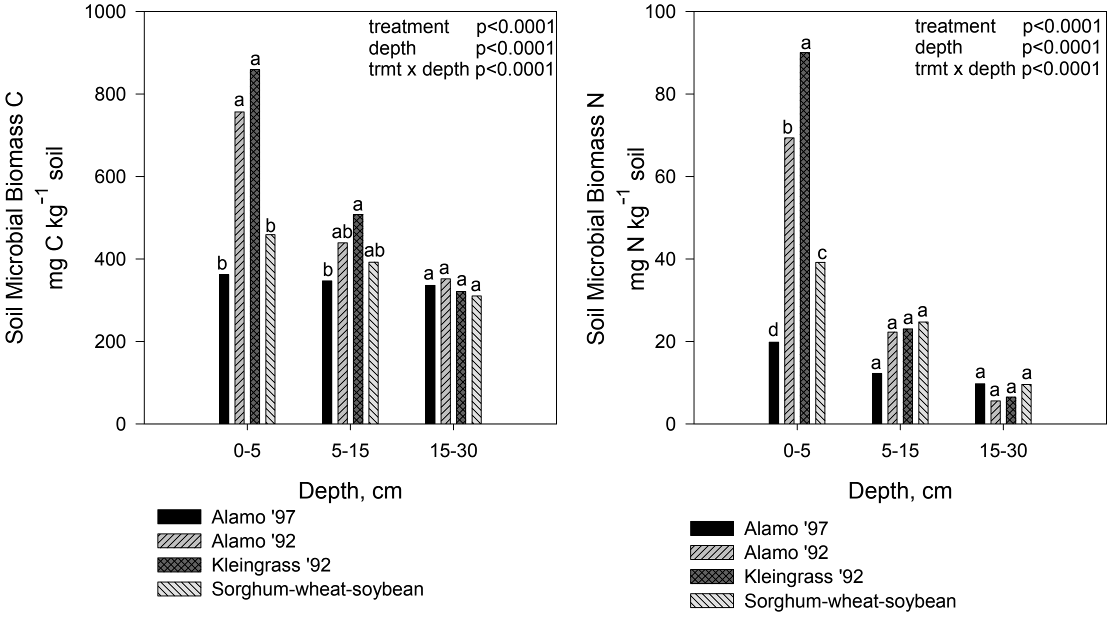
Figure 11a.

Figure 11b.

Figure 11. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. College Station, TX, March 1999.

Franzluebbers et al. (1998) found that SMBC and potential C mineralization exhibited similar relationships with tillage and cropping intensity as that observed for SOC, where SOC increased with cropping intensity as a result of greater C input.

Soil microbial biomass C at Stephenville at 0-5 cm was greatest under bermudagrass (1464 mg kg^{-1}), followed by Alamo planted in 1997 (761 mg kg^{-1}) and 1992 (728 mg kg^{-1}), and was lowest under the wheat-peanut rotation (420 mg kg^{-1}) (Fig. 12a). Significant differences were not found at 5-15- and 15-30-cm depths. Long-term pasture showed the highest value as expected (3.5 times more than cultivated soil). Alamo switchgrass planted in 1997 and 1992 had 81 and 73% more SMBC than the cultivated treatment, similar to results at Dallas.

Soil microbial biomass C at Yoakum at 0-5 cm followed a similar trend as that of SOC, being greatest under bermudagrass + poultry litter (245 mg kg^{-1}), followed by the oat-peanut rotation (176 mg kg^{-1}), and was lowest under Alamo switchgrass without N fertilization (122 mg kg^{-1}) and Alamo + 292 kg N ha^{-1} (98 mg kg^{-1}) (Fig. 13a). Soil microbial biomass C under bermudagrass + poultry litter was significantly greater than in soil under switchgrass treatments, but was not significantly different than that under oat-peanut. Soil microbial biomass C under oat-peanut was not significantly different than soil under switchgrass treatments. At 5-15 cm, SMBC was greatest under oat-peanut (132 mg kg^{-1}), followed by Alamo without N fertilization (68 mg kg^{-1}), bermudagrass + poultry litter (38 mg kg^{-1}), and Alamo + 292 kg N ha^{-1} (37 mg kg^{-1}). Incorporation of residues probably caused the increase of SMBC at this depth under the oat-peanut treatment. No significant differences due to vegetational treatments were observed in the 15-30-cm depth. Recent establishment of switchgrass treatments may account for the lower values compared to bermudagrass + poultry litter. The addition of poultry litter also may contribute to higher values under bermudagrass, similar to manure application.

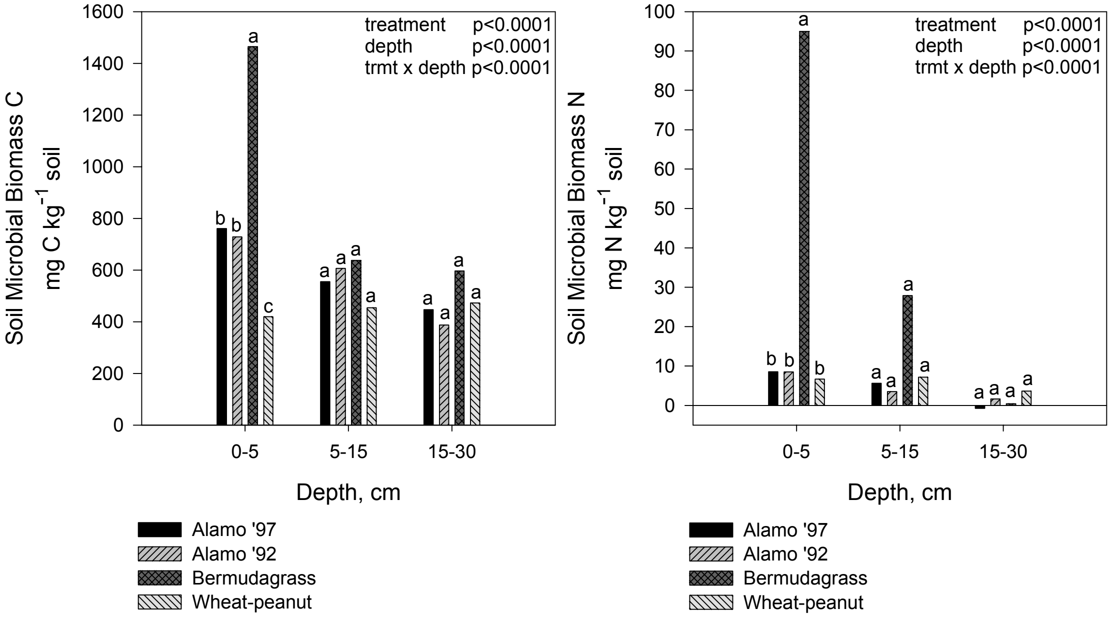

Figure 12a.

Figure 12b.

Figure 12. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Stephenville, TX, March 1999.

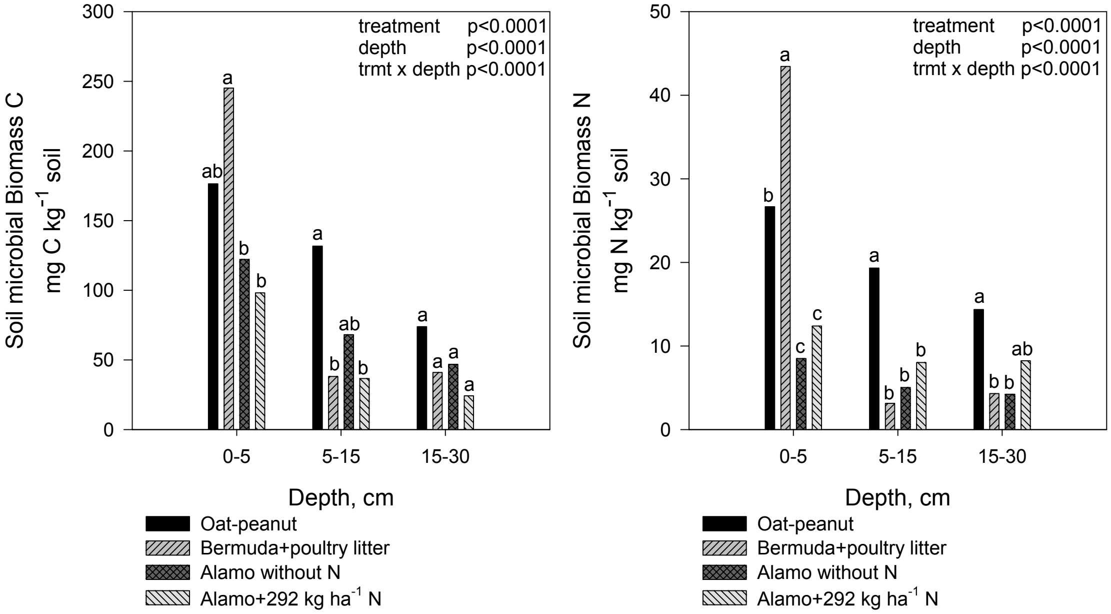

Figure 13a.

Figure 13b.

Figure 13. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Yoakum, TX, March 1999.

Soil Microbial Biomass Nitrogen

Soil microbial biomass N at Clinton at 0-5 cm was greatest under bahiagrass (56 mg kg^{-1}), followed by Alamo (20 mg kg^{-1}), Caddo (20 mg kg^{-1}), and forest (18 mg kg^{-1}) (Fig. 8b). The higher value under bahiagrass might be attributed to its longer stand age. No significant differences between switchgrass treatments and forest were the same as for SMBC results. Tree species and age of forest (Corre et al., 1999) may also be a factor affecting the outcome at this location.

Soil microbial biomass N at Hope at 0-5 cm was greatest in the forest soil (113 mg kg^{-1}), followed by bahiagrass (82 mg kg^{-1}), and was lowest under Caddo (36 mg kg^{-1}) and Alamo switchgrass (29 g kg^{-1}) (Fig. 9b). The higher value under forest might be due to tree species and age of forest. Bahiagrass/fescue has been established longer than switchgrass so the higher value would be expected. At 5-15-cm depth, forest again had significantly higher SMBN than the rest of the treatments. No significant differences were found at 15-30 cm. Recent establishment of switchgrass treatments may explain the low value of SMBN and SMBC compared to the other treatments, but they should increase with time.

Soil microbial biomass N at Dallas at 0-5 cm was greatest under bermudagrass (338 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (139 mg kg^{-1}) and 1997 (126 mg kg^{-1}), and was lowest under the wheat-cotton rotation (49 mg kg^{-1}) (Fig. 10b). Similar results were found at 5-15 and 15-30 cm. The bermudagrass is in a long-term grazed pasture that may help explain the high value of SMBN (6.8 times more SMBN than in cultivated wheat-cotton). Switchgrass planted in 1992 and 1997 had 2.8 and 2.6 more SMBN than the cultivated treatment. Several studies have shown that SMBC and N decrease with tillage (Franzluebbers, et al., 1994a, b, 1995a, b, 1998; Salinas-Garcia et al., 1997)

Soil microbial biomass N at College Station at 0-5 cm was greatest under kleingrass planted in 1992 (90 mg kg^{-1}), and second highest under Alamo switchgrass planted in 1992 (70 mg kg^{-1}), followed by the sorghum-wheat-soybean rotation (39 mg kg^{-1}), and was lowest under Alamo planted in 1997 (20 mg kg^{-1}) (Fig. 11b). No significant differences were found at 5-15 and 15-30-cm depths. Switchgrass planted in 1992 had 79% more SMBN than the cultivated treatment, and the cultivated treatment had 95% more SMBN than Alamo planted in 1997. The relatively high value for the cultivated treatment may be because it is intensively cropped and also includes the legume, soybean.

Soil microbial biomass N at Stephenville at 0-5 cm was greatest under bermudagrass (95 mg kg^{-1}), followed by Alamo planted in 1992 (9 mg kg^{-1}) and 1997 (9 mg kg^{-1}), and the wheat-peanut rotation (7 mg kg^{-1}) (Fig. 12b). Bermudagrass at this location is in a long-term pasture that also receives dairy manure applications. The SMBN concentration under the wheat-peanut rotation was not significantly different than that under switchgrass treatments, possibly because the rotation includes peanut which is a legume, and also because there is cattle grazing of wheat. These two factors may provide more N to the microbial population in this treatment. No significant differences were evident at 5-15- and 15-30-cm depths.

Treatments at Yoakum influenced SMBN similarly to SMBC, with values for SMBN at 0-5 cm being greatest under bermudagrass + poultry litter (43 mg kg^{-1}), followed by the oat-peanut rotation (27 mg kg^{-1}), and were lowest under Alamo + 292 kg N ha^{-1} (12 mg kg^{-1}), and Alamo without N fertilization (9 mg kg^{-1}) (Fig. 13b). At 5-15 cm, the oat-peanut rotation showed significantly greater SMBN than the rest of treatments. At 15-30 cm, the oat-peanut rotation also had more SMBN than the rest of treatments except for Alamo + 292 kg N ha^{-1}. Incorporation of residues and peanut in the rotation possibly make N more available to the microbial population deeper in the soil.

Carbon Mineralization

Carbon mineralized in 24 days should theoretically be highly related to SMBC and this was observed in most situations. Results from Dallas, for example, demonstrate the close association between SMBC and soil C mineralized at this location (Fig. 14). This linear regression demonstrates that SMBC is a good predictor (r^2=0.85) of C mineralization.

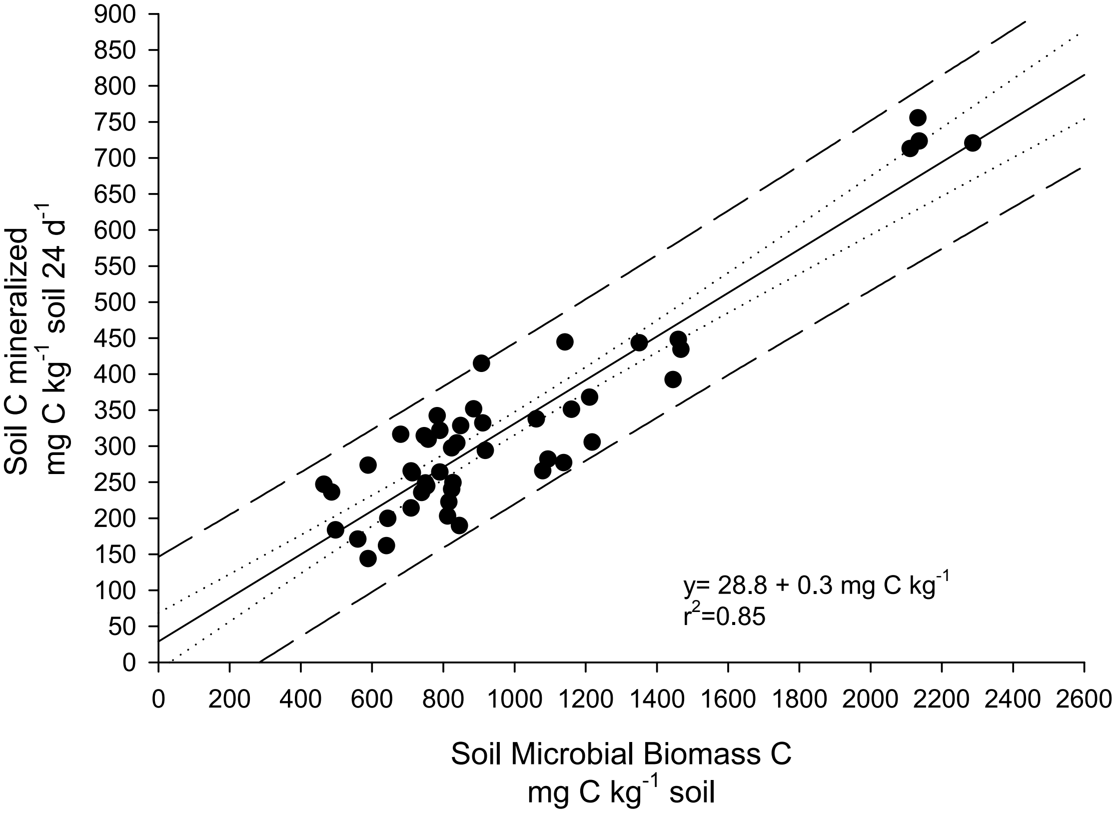

Figure 14. Regression of soil C mineralized in 24 days vs. soil microbial biomass C. Dallas, TX, March 1999.

Carbon mineralization generally followed similar trends as those of SMBC, and decreased with depth as did SMBC.

Soil C mineralization at Clinton at 0-5 cm was greatest under bahiagrass (462 mg kg^{-1}) and forest (406 mg kg^{-1}), and was lowest under Alamo (286 mg kg^{-1}) and Caddo switchgrass (284 mg kg^{-1}) (Fig. 15a). At Clinton, C mineralization also followed trends similar to SOC, where bahiagrass and forest had the greatest amount of SOC. Significantly more C was mineralized under forest (42% more) compared to switchgrass probably because of greater C input under forest and the recent establishment of switchgrass treatments. The fact that there were not significant differences for SMBC and N under forest compared to switchgrass treatments, however, may indicate that switchgrass residues or its extensive root biomass may provide a better quality substrate for the microbial population, resulting in faster nutrient cycling under switchgrass at this location. Tree species and age of forest may also affect these results. The higher value under bahiagrass is expected because of its longer establishment. Similar differences were seen at 5-15 and 15-30 cm, but differences at 15-30 cm were not significant.

Soil C mineralization at Hope at 0-5 cm was greatest under bahiagrass (450 mg kg^{-1}) > forest soil (358 mg kg^{-1}) ≥ Caddo (314 mg kg^{-1}) ≥ Alamo switchgrass (260 mg kg^{-1}) (Fig. 16a). No significant differences were observed for 5-15- and 15-30-cm depths. Higher values under bahiagrass and forest again are expected since one is a long-term pasture and the other has a high input of C from trees. Lower values under switchgrass treatments may be explained by their recent establishment. Forest soil and that from bahiagrass also showed the highest values of SMBC at this location. Contrary to results at Clinton, C mineralization at Hope was not different for the forest and Caddo switchgrass.

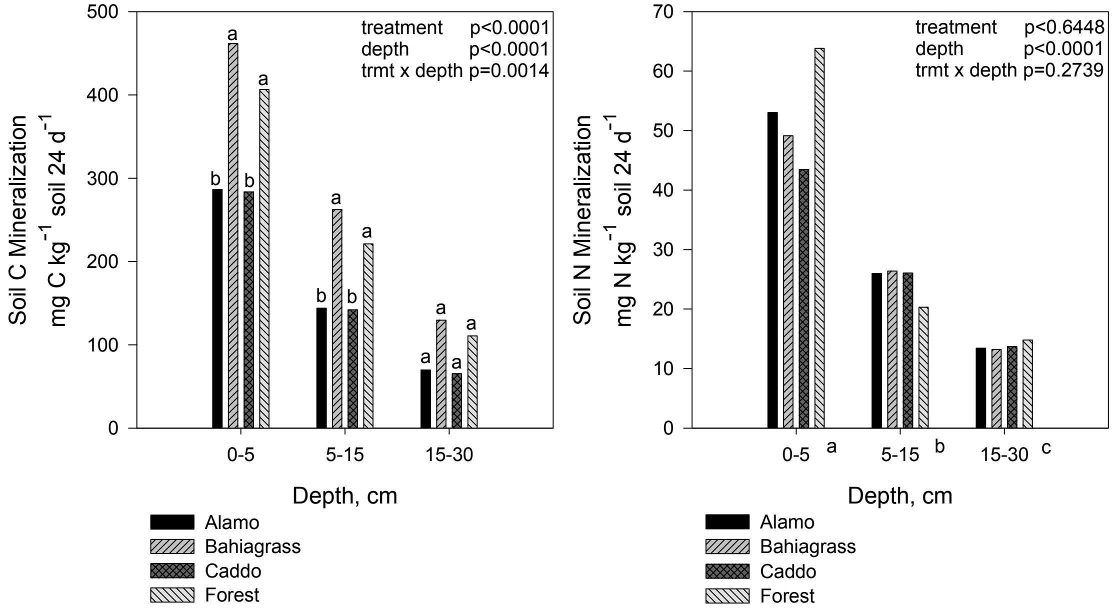

Figure 15a.

Figure 15b.

Figure 15. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Clinton, LA, March 1999.

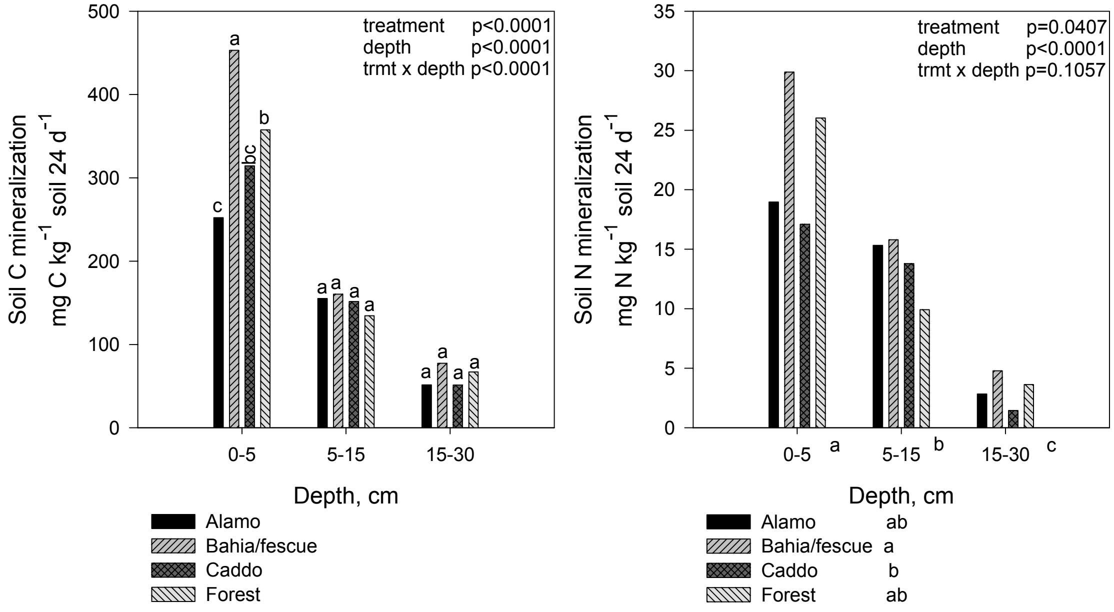

Figure 16a.

Figure 16b.

Figure 16. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Hope, AR, March 1999.

At Dallas, C mineralization at 0-5 cm was greatest under bermudagrass (728 mg kg^{-1}) > Alamo switchgrass planted in 1992 (373 mg kg^{-1}) > Alamo planted in 1997 (283 mg kg^{-1}) ≥ wheat-cotton rotation (219 mg kg^{-1}) (Fig. 17a). There was 70% more mineralizable C under Alamo switchgrass planted in 1992 than under the wheat-cotton cultivated treatment. Previous studies have found similar results where mineralizable C was greatest under NT (similar to permanent vegetative covers) than under CT where physical disruption of soil occurs (Franzluebbers, et al., 1994a, b, 1995a, b, 1998, 2000; Salinas-Garcia et al., 1997). Results for deeper depths followed similar trends.

Carbon mineralized at College Station at 0-5 cm was greatest under kleingrass (348 mg kg^{-1}) ≥ Alamo planted in 1992 (298 mg kg^{-1}) > sorghum-wheat-soybean rotation (156 mg kg^{-1}) = Alamo planted in 1997 (155 mg kg^{-1}) (Fig. 18a). Similar differences were observed at 5-15 cm, and no differences were found at 15-30 cm. There was 91% more mineralizable C under Alamo switchgrass planted in 1992 than under the sorghum-wheat-soybean rotation. Mineralizable C under Alamo planted in 1997 and the sorghum-wheat-soybean rotation were not significantly different. The two high residue crops and the high cropping intensity of the rotation may explain why the cultivated treatment has a similar amount of mineralizable C to that under Alamo planted in 1997. Franzluebbers et al. (1998) found that potential C mineralization increased with cropping intensity.

Soil C mineralized at Stephenville at 0-5 cm was greatest under bermudagrass (516 mg kg^{-1}) > Alamo switchgrass planted in 1992 (301 mg kg^{-1}) > Alamo planted in 1997 (232 mg kg^{-1}) > wheat-peanut rotation (90 mg kg^{-1}) (Fig. 19a). The high value of mineralizable C is expected under bermudagrass since it is a long-term pasture and also receives applications of dairy manure. As expected, the switchgrass treatments had greater mineralizable C than the wheat-peanut cultivated treatment.

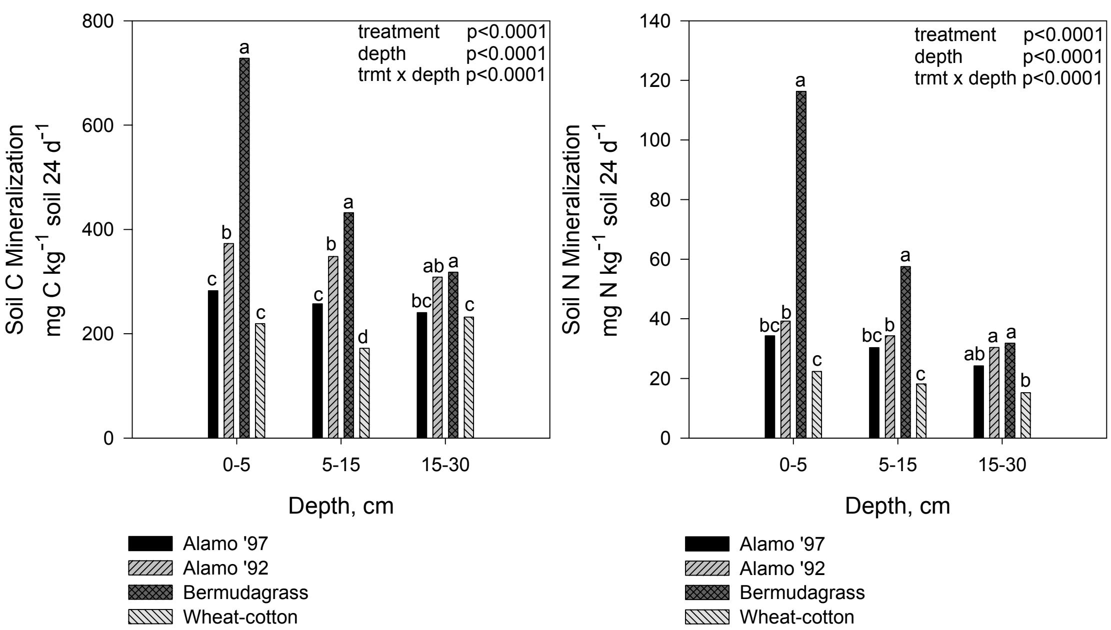
Figure 17a.

Figure 17b.

Figure 17. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Dallas, TX, March 1999.

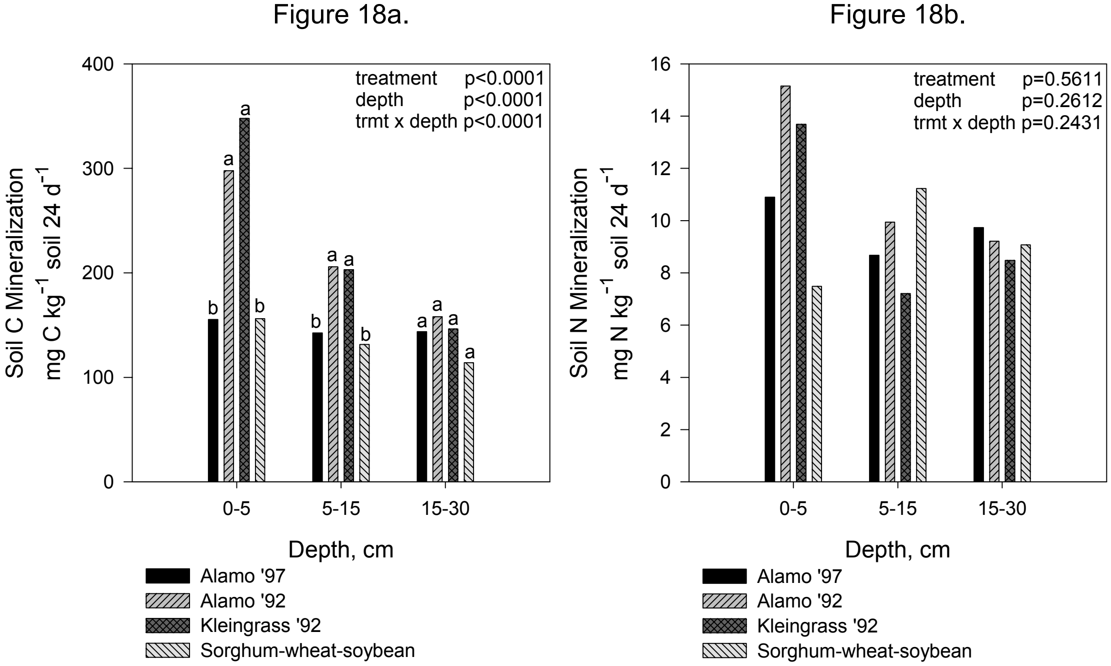
Figure 18a.

Figure 18b.

Figure 18. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. College Station, TX, March 1999.

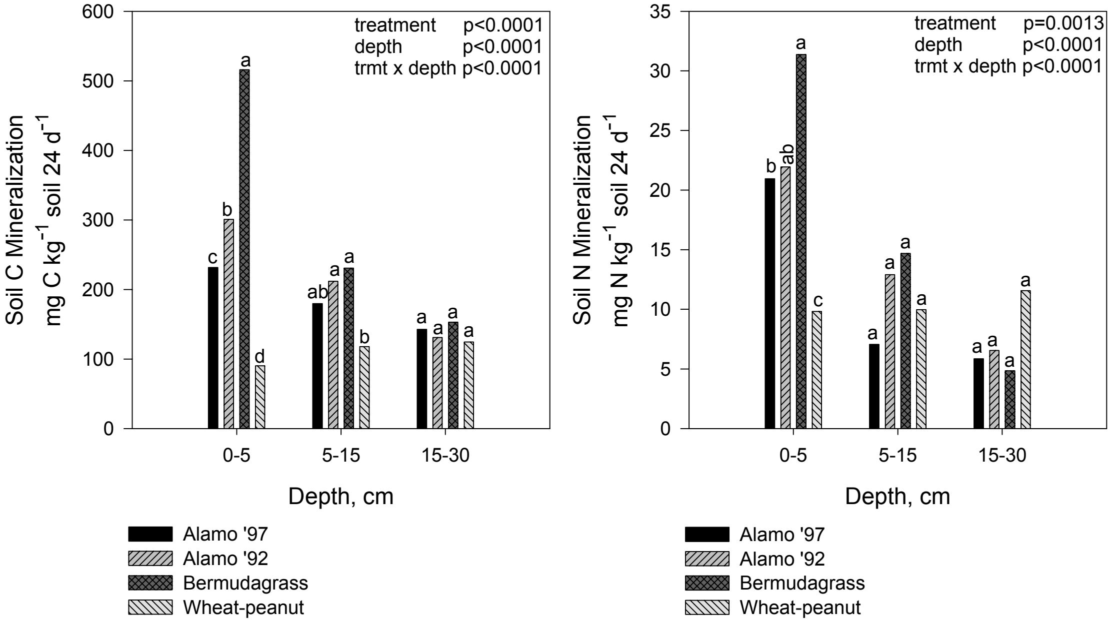

Figure 19. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Stephenville, TX, March 1999.

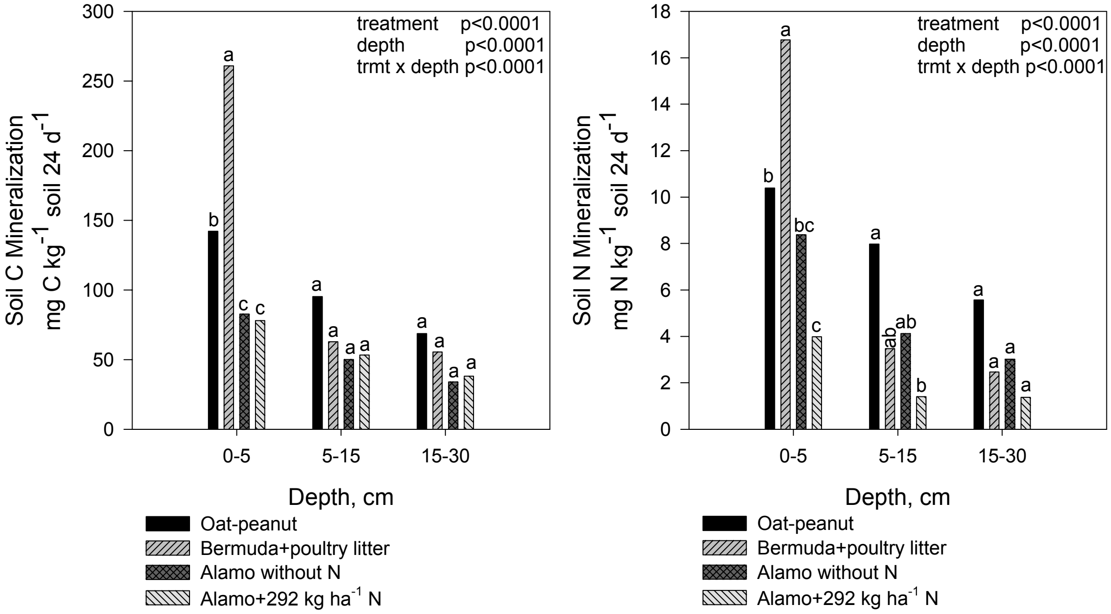

Figure 20. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Yoakum, TX, March 1999.

Alamo switchgrass planted in 1992 and 1997 had 3.3 and 2.6 times more mineralizable C than the cultivated treatment, respectively. Similar results were found by Franzluebbers et al. (1994a,b) and Salinas-García et al. (1997), where cultivated soils showed lower values of C mineralization and other soil quality parameters than soils where no disturbance was occurring.

Soil C mineralized at Yoakum at 0-5 cm was greatest under bermudagrass + poultry litter (261 mg kg^{-1}) > oat-peanut (142 mg kg^{-1}) > Alamo without N fertilization (83 mg kg^{-1}) = Alamo + 292 kg N ha^{-1} (78 mg kg^{-1}) (Fig 20a). Recent establishment of switchgrass may account for the low C mineralization. No differences were noted at lower depths.

Nitrogen Mineralization

Soil N mineralized in 24 days generally followed a pattern similar to that of C mineralization. There was also usually a close association between SMBC and N mineralization, as shown by results from Dallas samples (Fig. 21) with 95% confidence (dotted) and prediction (long dash) intervals. This regression demonstrates that SMBC is also a good predictor (r^2=0.90) of N mineralization.

At Clinton, soil N mineralized under the different vegetational treatments was not significantly different, averaging 30.5 mg N kg^{-1} soil over 24 days (Fig. 15b). Switchgrass, even though recently established, was not significantly different compared to long-term bahiagrass and forest. This result suggests that switchgrass residues may be more easily decomposed and recycled by the microbial population.

Soil N mineralization at Hope followed the sequence of bahiagrass (16 mg kg^{-1}) ≥ forest (13 mg kg^{-1}) and Alamo switchgrass (12 mg kg^{-1}) ≥ Caddo switchgrass (10 mg kg^{-1}) (Fig. 16b). Switchgrass residues may be more easily decomposed and recycled through the microbial population. This is good from the point of view of plant nutrition because N will be available for plant uptake almost in the same amount as that under the longer-term treatments, even though switchgrass treatments were more recently established.

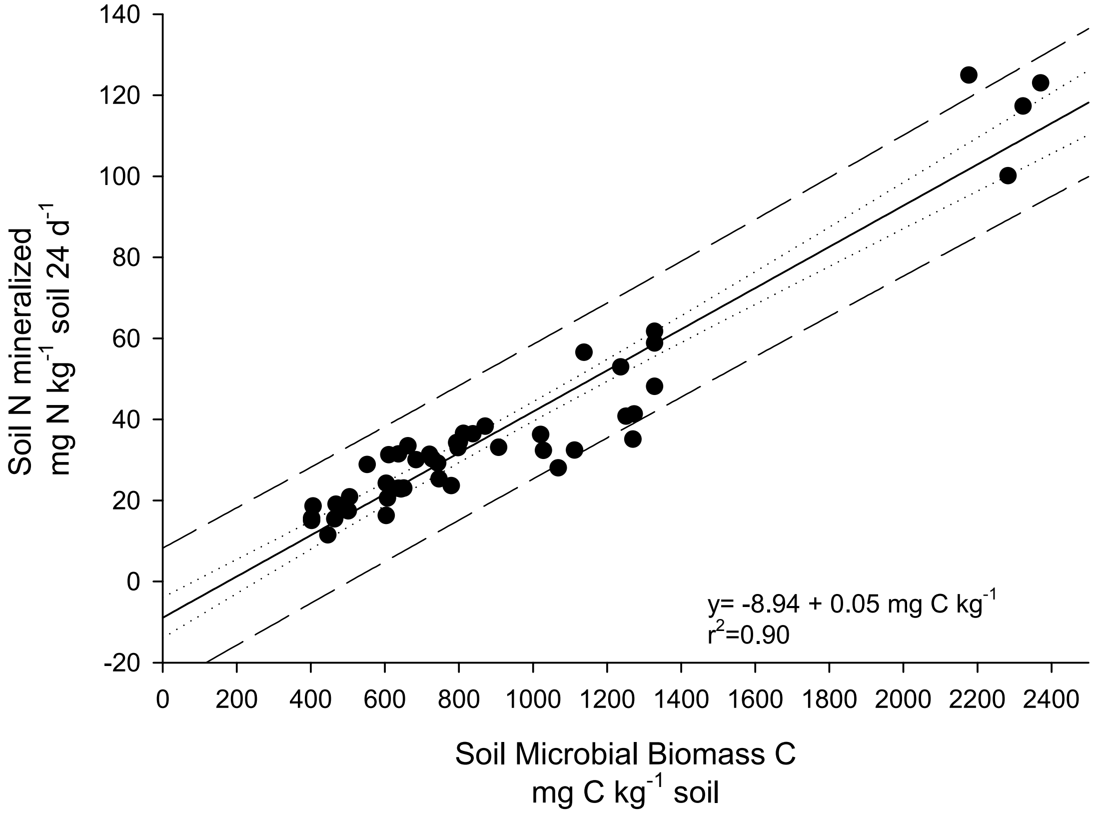

Figure 21. Regression of soil N mineralized in 24 days vs. soil microbial biomass C. Dallas, TX, December 1999.

Soil N mineralized at Dallas at 0-5 cm was greatest under bermudagrass (116 mg kg^{-1}) > Alamo planted in 1992 (39 mg kg^{-1}) ≥ Alamo planted in 1997 (34 mg kg^{-1}) ≥ wheat-cotton rotation (22 mg kg^{-1}) (Fig. 17b). Similar differences were also observed at 5-15- and 15-30-cm depths. Previous studies have found similar results where mineralizable N was greater under NT (comparable to permanent vegetative covers) than under CT where physical disruption of soil occurs (Franzluebbers, et al., 1994a,b, 1995a,b; Salinas-Garcia et al., 1997).

Switchgrass planted in 1992 and 1997 had 77 and 55% greater mineralizable N concentration than the cultivated soil treatment.

Soil N mineralization at College Station was not significantly affected by vegetational treatment or depth and averaged 10.7 mg N kg^{-1} soil (Fig. 18b). The use of two high residue crops and soybean (N_2-fixing plant), and incorporation of residues into the soil (more exposure of residues to microbial decomposition) may explain why mineralizable N under the sorghum-wheat-soybean rotation was not different than the rest of the treatments.

At Stephenville, N mineralization at 0-5 cm was greatest under bermudagrass (31 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (22 mg kg^{-1}) and 1997 (21 mg kg^{-1}), and was lowest under the wheat-peanut rotation (10 mg kg^{-1}) (Fig. 19b). Results were similar to those at Dallas where the cultivated soil had the lowest concentration of mineralizable N. At Stephenville, Alamo switchgrass planted in 1992 and 1997 both had more than twice the mineralizable N than the cultivated soil. No differences were observed at deeper depth.

At Yoakum at 0-5 cm, N mineralization was greatest under bermudagrass + poultry litter (17 mg kg^{-1}), followed by the oat-peanut rotation (10 mg kg^{-1}) and Alamo without N fertilization (8 mg kg^{-1}), and was lowest under Alamo + 240 lbs N Acre^{-1} (4 mg kg^{-1}) (Fig 20b). Oat-peanut had significantly more mineralizable N than Alamo + 292 kg N ha^{-1}, but was not different from Alamo without N.

Basal Soil Respiration

Basal soil respiration (BSR) represents the steady state activity of soil microbial biomass, and generally followed the same trend as that of C mineralized in 24 days.

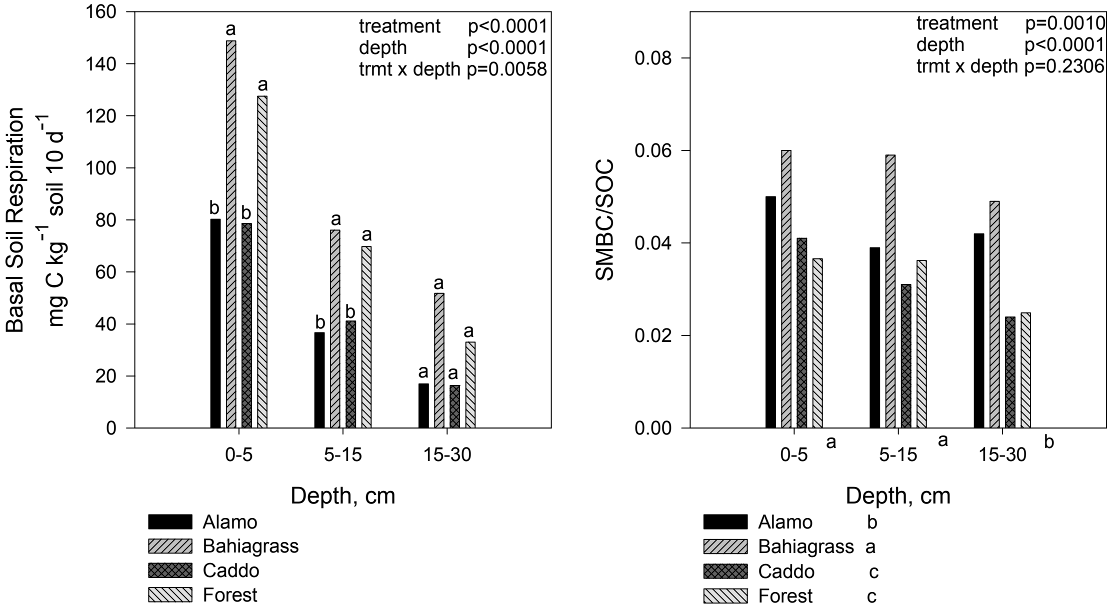
Figure 22a.

Figure 22b.

Figure 22. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Clinton, LA, March 1999.

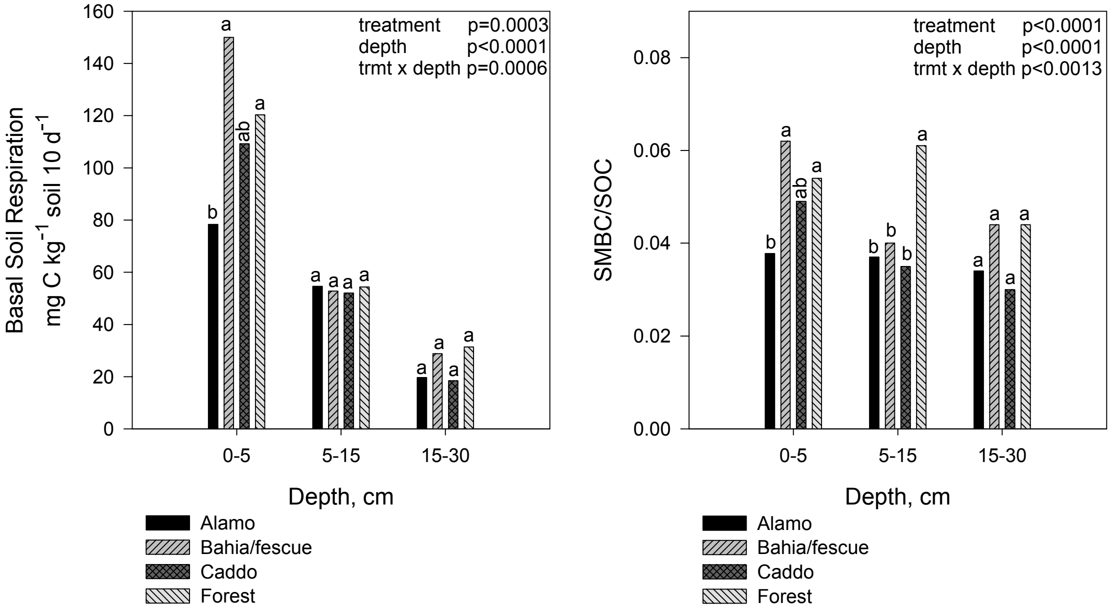
Figure 23a.

Figure 23b.

Figure 23. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Hope, AR, March 1999.

At Clinton at 0-5 cm, BSR was greatest under bahiagrass (149 mg kg^{-1}) and forest (128 mg kg^{-1}), and lowest under Alamo (80 mg kg^{-1}) and Caddo switchgrass (79 mg kg^{-1}) (Fig. 22a). Similar differences were evident at 5-15 cm, but no significant differences occurred at 15-30-cm depth. The highest value under long-term bahiagrass was expected since this treatment has been consistently higher for all studied parameters. The difference between forest and switchgrass treatments could be attributed to the higher C input under forest, and the recent establishment of the switchgrass treatments.

Basal soil respiration at Hope at 0-5 cm was greatest under bahiagrass (150 mg kg^{-1}), followed by forest (120 mg kg^{-1}) and Caddo switchgrass (109 mg kg^{-1}), and was lowest under Alamo switchgrass (79 mg kg^{-1}) (Fig. 23a). No significant differences were observed at lower depth.

At Dallas, BSR at 0-5 cm was greatest under bermudagrass (223 mg kg^{-1}), second highest under Alamo switchgrass planted in 1992 (118 mg kg^{-1}), followed by Alamo planted in 1997 (87 mg kg^{-1}), and lowest under the wheat-cotton rotation (63 mg kg^{-1}) (Fig. 24a). Similar differences were observed at 5-15 cm, and no significant differences were evident at 15-30 cm. Basal soil respiration follows similar trends as other soil characteristics at this location, with long-term bermudagrass pasture showing the highest values, followed by swithgrass treatments and lowest under cultivated soil.

At College Station, BSR at 0-5 cm was greatest under kleingrass planted in 1992 (105 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (85 mg kg^{-1}), and lowest under Alamo planted in 1997 (49 mg kg^{-1}) and the sorghum-wheat-soybean rotation (44 mg kg^{-1}) (Fig. 25a). Similar trends were noted at 5-15 cm, and no significant differences occurred at 15-30 cm. Basal soil respiration follows similar trends as other soil characteristics at this location, with kleingrass and Alamo planted in 1992 showing the greatest values, followed by sorghum-wheat-soybean and Alamo planted in 1997.

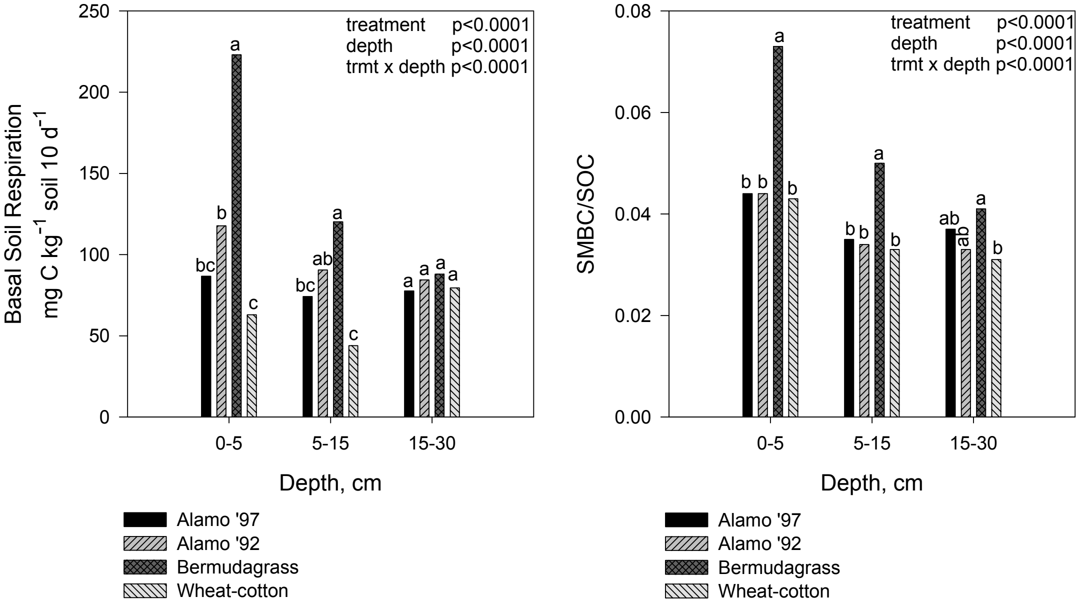

Figure 24a.

Figure 24b.

Figure 24. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Dallas, TX, March 1999.

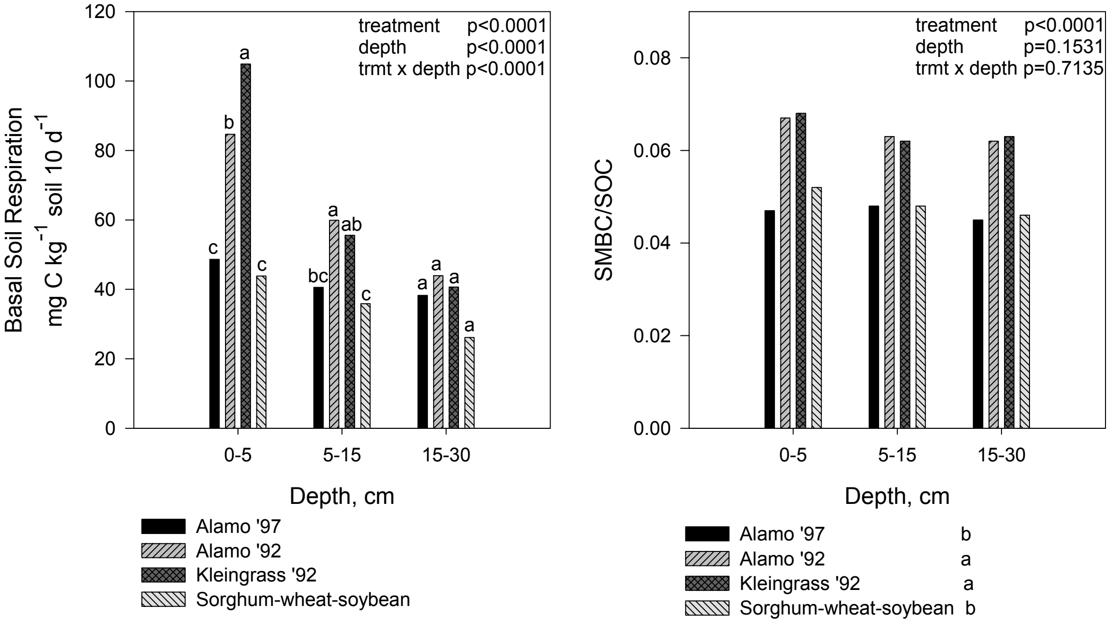

Figure 25a.

Figure 25b.

Figure 25. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. College Station, TX, March 1999.

Basal soil respiration at Stephenville at 0-5 cm was greatest under bermudagrass (148 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (90 mg kg^{-1}) and 1997 (68 mg kg^{-1}), and was lowest under wheat-peanut rotation (24 mg kg^{-1}) (Fig. 26a). Similar effects occurred at 5-15 cm, and no significant differences occurred at 15-30 cm. Basal soil respiration followed similar trends as other soil characteristics at this location, with long-term bermudagrass showing the highest values, followed by switchgrass treatments and then the cultivated soil.

Basal soil respiration at Yoakum followed trends of C mineralization at 0-5 cm and was in the order: bermudagrass + poultry litter (83 mg kg^{-1}) > oat-peanut (35 mg kg^{-1}) = Alamo + 292 kg N ha^{-1} (21 mg kg^{-1}) = Alamo without N fertilization (22 mg kg^{-1}) (Fig 27a).

Ratio of Soil Microbial Biomass Carbon:Soil Organic Carbon

The portion of SOC that exists as SMBC has previously been used as a sensitive indicator of changes in soil quality. Increasing values of SMBC/SOC may indicate improvement in soil quality. At Clinton, SMBC/SOC was greatest under bahiagrass (0.057), followed by Alamo switchgrass (0.044), and lowest under Caddo (0.033) and forest (0.033) (Fig. 22b). Low values for forest may indicate lower quality of C inputs.

At Hope, SMBC/SOC at 0-5 cm was greatest under bahiagrass (0.062), forest (0.054), and Caddo (0.048), and lowest under Alamo (0.038) (Fig. 23b).

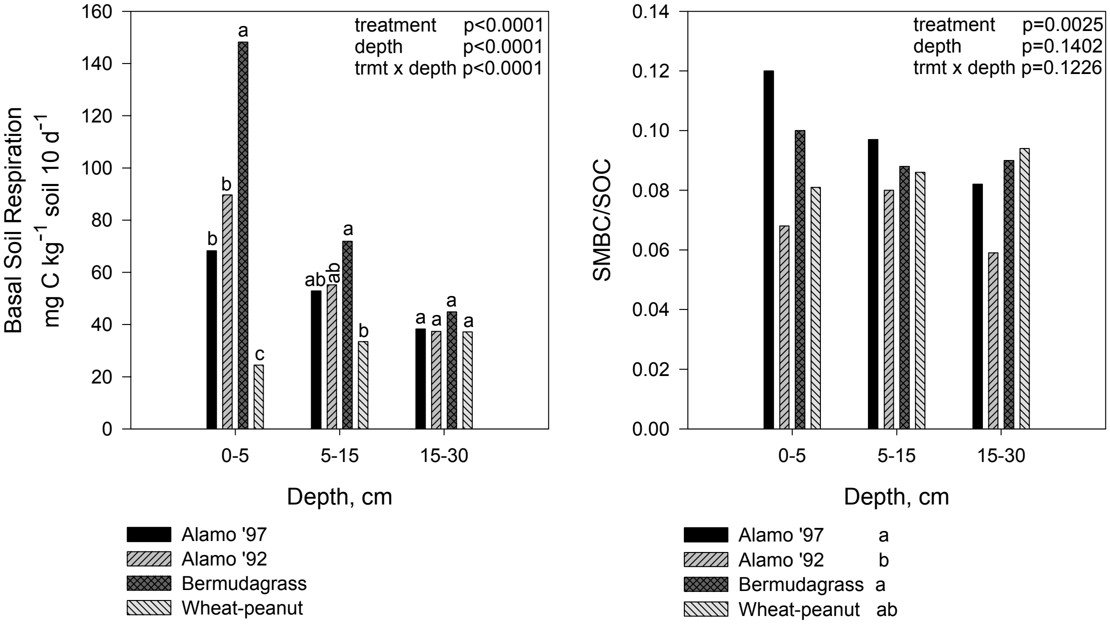

Figure 26a.

Figure 26b.

Figure 26. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Stephenville, TX, March 1999.

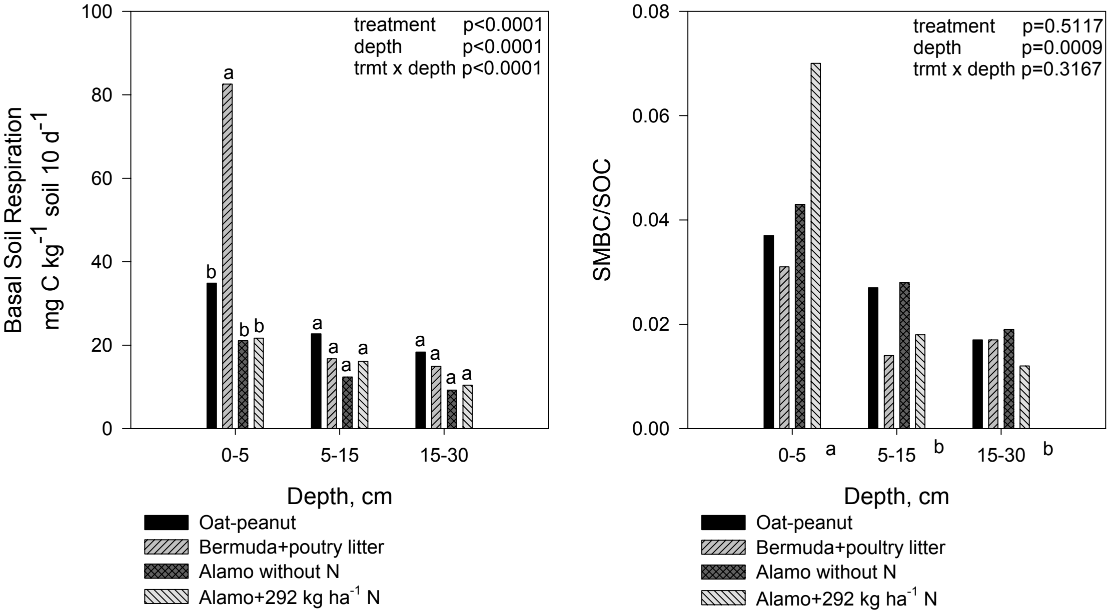

Figure 27a.

Figure 27b.

Figure 27. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Yoakum, TX, March 1999.

The ratio at 5-15 cm for forest was significantly higher (0.061) than the other vegetational treatments. The difference between forest and switchgrass treatments at Hope vs. Clinton is not clear, as has been previously stated. Differences in tree species may account for the results.

Ratio of SMBC/SOC at Dallas at 0-5 cm was greatest under bermudagrass (0.073), followed by Alamo planted in 1992 (0.045), 1997 (0.045), and the wheat-cotton rotation (0.044). The same pattern of differences was observed at 5-15 cm, but differences were less pronounced at the 15-30-cm depth (Fig. 24b). The ratio of SMBC/SOC under wheat-cotton was not significantly different than that under switchgrass. Incorporation of residues in the rotation may have allowed the microbial population (by a greater exposure of residues to microbes) to increase even though the SOC content under the cultivated treatment was the lowest. Conventional tillage operations such as plowing promote loss of SOM through crop residue incorporation, disruption of soil aggregates, and increased aeration (Balesdent et al., 1990).

At College Station SMBC/SOC was greatest under kleingrass (0.069) and Alamo switchgrass planted in 1992 (0.068), and lowest under the sorghum-wheat-soybean rotation (0.053) and Alamo planted in 1997 (0.048) (Fig. 25b). Permanent vegetative cover with no soil disturbance over the long-term apparently increases SMBC/SOC at this location.

At Stephenville, SMBC/SOC was greatest under switchgrass planted in 1997 (0.099) and bermudagrass (0.096), followed by wheat-peanut (0.087) and Alamo planted in 1992 (0.070) (Fig. 26b). At this location, Alamo switchgrass planted in 1997 and the wheat-peanut rotation were not significantly different for this characteristic, similar to results at Dallas where the wheat-cotton rotation was not significantly different from either Alamo planted in 1992 or 1997 for SMBC/SOC. Incorporation of residues in cultivated treatments may help increase SMBC by exposing more plant material to microbial degradation compared to treatments where no disruption occurs. This increase, however may be temporary. Loss of SOC as a result of soil cultivation has been well documented (Hass et al., 1957; Mann, 1986; Franzluebbers et al., 1998). It is not clear why the ratio for Alamo planted in 1997 was significantly greater than for Alamo planted in 1992. The lower accumulation of SOC combined with the more easily decomposable residue from the newly established 1997 Alamo planting may account for this outcome. The SOC content under Alamo planted in 1992 was significantly greater than that under Alamo planted in 1997, but the SMBC and SMBN concentrations were not different.

SMBC/SOC at Yoakum was in the order: Alamo + 292 kg N ha^{-1} (0.033), Alamo without N fertilization (0.030), oat-peanut rotation (0.027), and switchgrass+poultry litter (0.027) (Fig 27b). The highest value of SMBC/SOC across all locations was exhibited under Alamo planted in 1997 (0.099) at Stephenville, TX.

December Sampling

Soil Organic Carbon

Soil organic C at Clinton showed a significant *season x vegetational treatment* interaction (p=0.0042; df=3,72). Soil organic C averaged across depth was greatest under bahiagrass (12 g kg^{-1}), second highest under Alamo switchgrass (11 g kg^{-1}), and was lowest under forest (9 g kg^{-1}) and Caddo switchgrass (9 g kg^{-1}) (Fig. 28a). Soil organic C under switchgrass treatments was not significantly different than that under forest soil, contrary to findings in March where SOC under forest > switchgrass treatments. As previously stated, differences between forest soil and switchgrass were not consistent (Corre et al., 1999). Long-term bahiagrass was significantly greater than forest, similar to findings by Franzluebbers et al. (2000) where SOC and N at a depth of 0-20 cm under grass-based management were greater than forest or cropland.

Soil organic C at Hope also showed a significant *season x vegetational treatment x depth* interaction (p=0.0197; df=6,68). At 0-5 cm, SOC was greatest under forest (15 g kg^{-1}) > Alamo switchgrass (11 g kg^{-1}) = Caddo switchgrass (9 g kg^{-1}) = bahiagrass/fescue (7 g kg^{-1}) (Fig. 29a). At 5-15 cm, SOC was significantly greater under Alamo (10 g kg^{-1}) = Caddo (10 g kg^{-1}) > forested area (7 g kg^{-1}) = bahiagrass/fescue (6 g kg^{-1}). During March, differences were apparent only at 5-15 cm, but during December differences were noted at 0-5- and 5-15-cm depths. Similar to March, SOC under forest during December was also lower than switchgrass treatments at 5-15 cm. Soil organic C at 0-5 cm significantly changed under forest and bahiagrass/fescue from March to December, increasing in forest soil from 12 to 15 g kg^{-1} and decreasing from 13 to 9 g kg^{-1} under bahiagrass/fescue. The increase under forest at 0-5 cm is probably due to high C input from leaves at the surface with time.

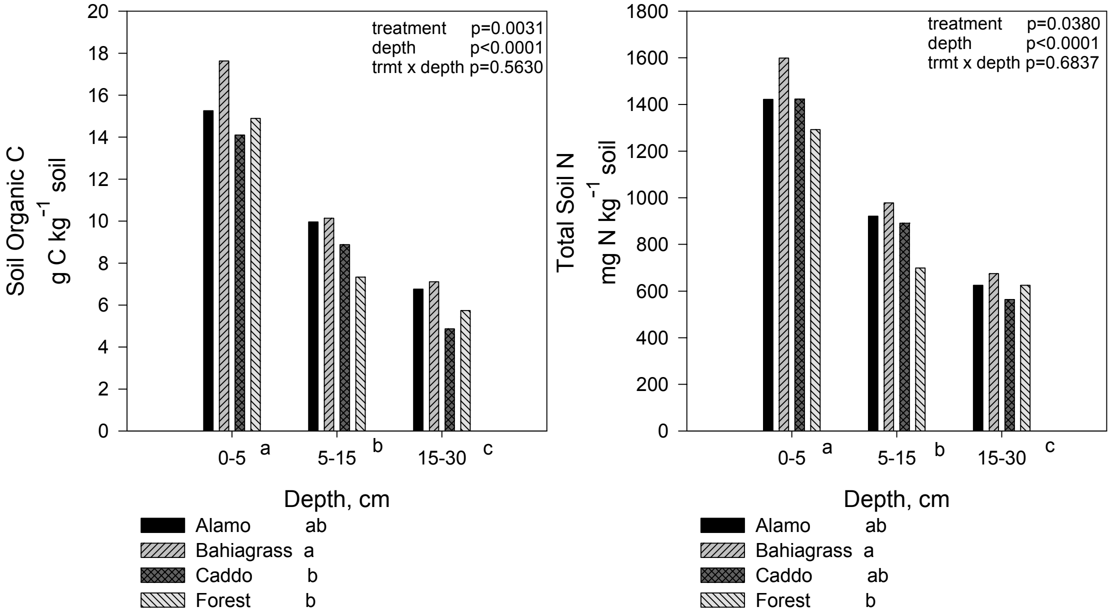

Figure 28a.

Figure 28b.

Figure 28. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Clinton, LA, December 1999.

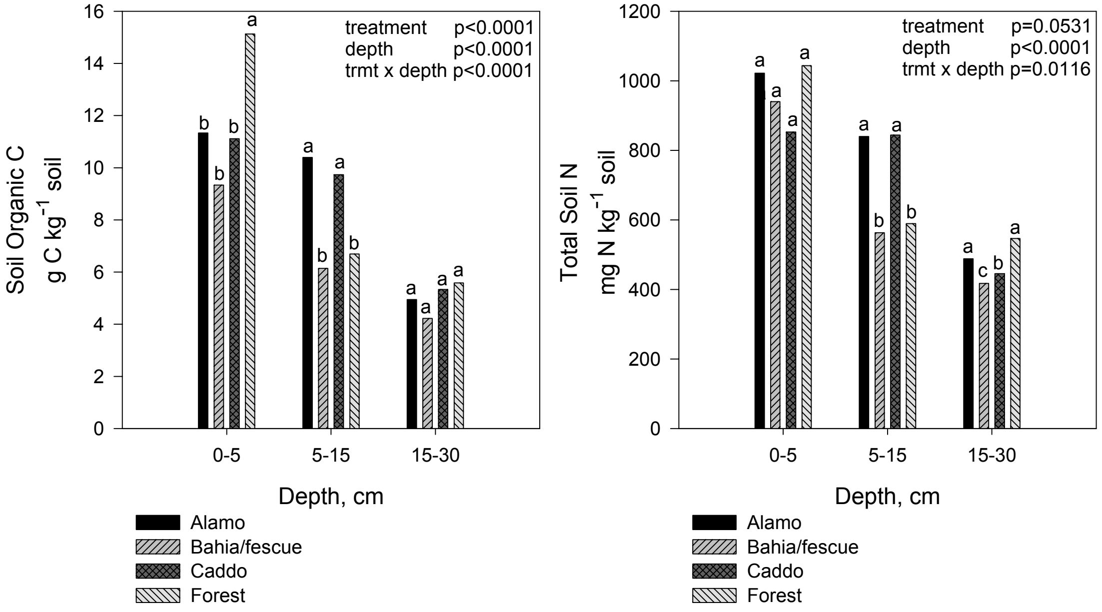

Figure 29a.

Figure 29b.

Figure 29. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Hope, AR, December 1999.

The decrease under bahiagrass/fescue was probably due to C mineralization. At the March sampling, bahiagrass/fescue had the greatest SMBC value at 0-5 cm. Soil organic C under Alamo (12 to 11 g kg^{-1}) and Caddo (10 to 11 g kg^{-1}) switchgrass did not change significantly from March to December at any depth. Differences between forest and switchgrass soils were not consistent as previously found by Corre et al. (1999).

Soil organic C at Dallas showed a significant *season x vegetational treatment x depth* interaction (p<0.0001; df=6,72). Soil organic C at 0-5 cm was greatest under bermudagrass (54 g kg^{-1}), followed by Alamo switchgrass planted in 1992 (27 g kg^{-1}) and 1997 (25 g kg^{-1}), and was lowest under the wheat-cotton rotation (17 g kg^{-1}) (Fig. 30a). Alamo switchgrass planted in 1992 and 1997 had 59 and 47% more SOC than the cultivated rotation, respectively, at this depth. At 5-15 cm, bermudagrass and switchgrass treatments were not significantly different, but the wheat-cotton rotation was still the lowest, similar to findings by Franzluebbers et al. (2000) where grass-based management systems had greater SOC and N compared to forest or cropland. Similar differences were observed at 15-30 cm. Soil organic C under bermudagrass at 0-5 cm increased significantly from 30 g kg^{-1} to 54 g kg^{-1} from March to December. This increase may be from above ground biomass and roots during growth and manure deposition from grazing cattle. Soil organic C did not change significantly from March to December under Alamo switchgrass planted in 1992 (27 to 27 g kg^{-1}), Alamo switchgrass planted in 1997 (25 to 25 g kg^{-1}), and the wheat-cotton rotation (19 to 17 g kg^{-1}) for any depth.

At College Station, SOC did not exhibit a significant *season x vegetational treatment* interaction (p=0.8048; df=3,72). At 0-5 cm, SOC was greatest under Alamo switchgrass (12 g kg^{-1}) and kleingrass planted in 1992 (12 g kg^{-1}) = sorghum-wheat-soybean rotation (11 g kg^{-1}) ≥ Alamo planted in 1997 (8 g kg^{-1}) (Fig. 31a).

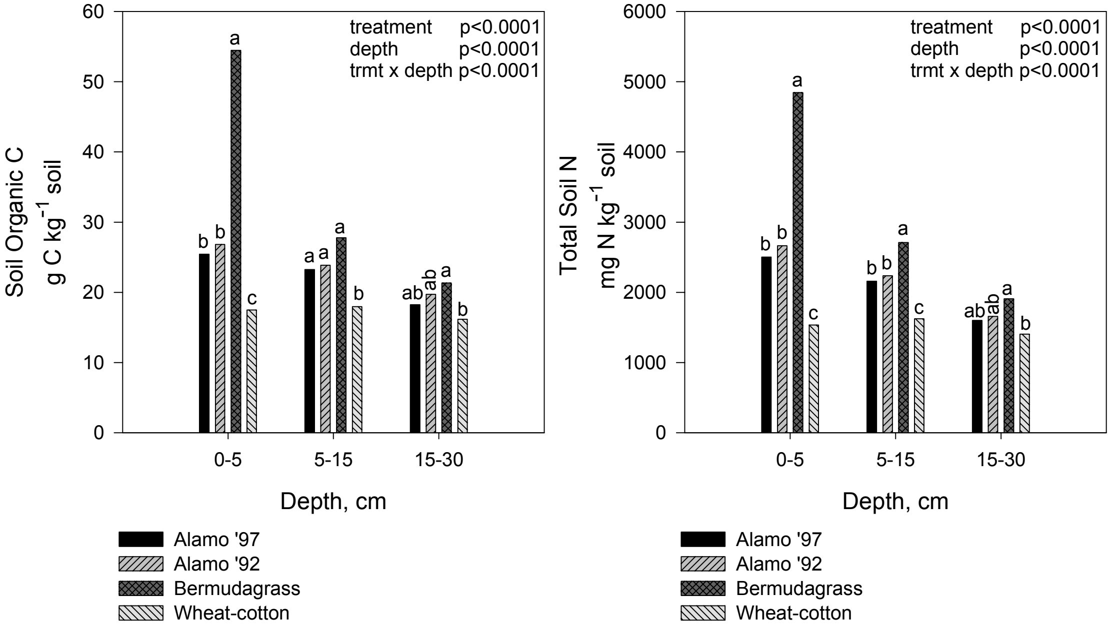

Figure 30a.

Figure 30b.

Figure 30. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Dallas, TX, December 1999.

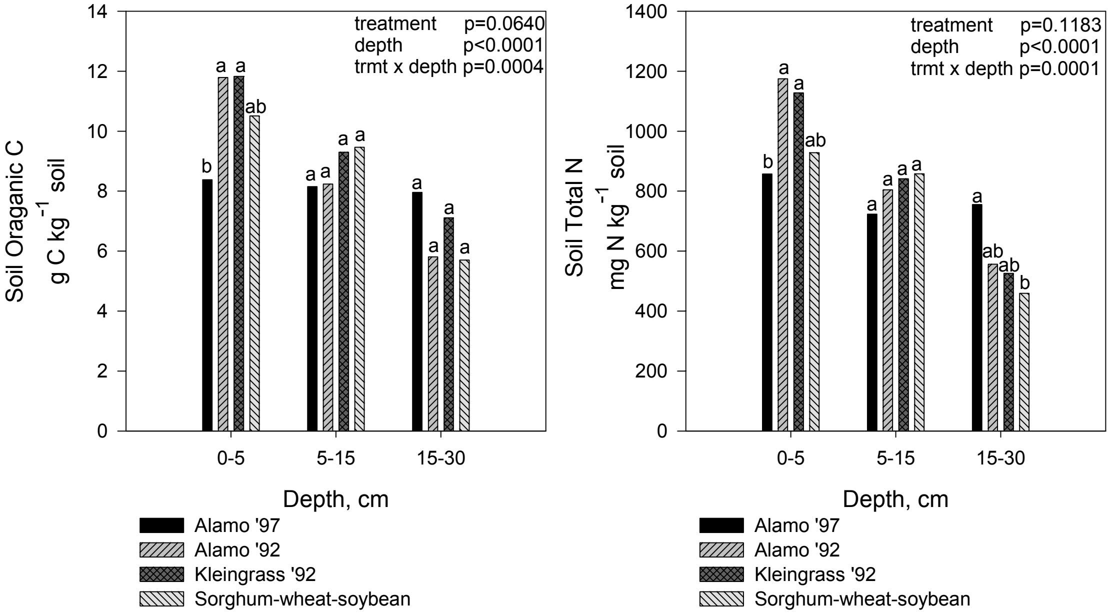

Figure 31a.

Figure 31b.

Figure 31. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. College Station, TX, December 1999.

The use of the two high-residue crops, sorghum and wheat, may help explain why the cultivated treatment was not different from Alamo switchgrass and kleingrass, similar to findings in March. Return of crop residues in this rotation at the end of the growing season may also have increased SOC for the rotation in December. Franzluebbers et al. (1998) found that SOC increased with cropping intensity. No significant differences at 5-15- and 15-30-cm depths were found.

Soil organic C at Stephenville showed a significant *season x vegetational treatment x depth* interaction ($p<0.0423$; df=6,71). Soil organic C at 0-5 cm was greatest under bermudagrass (17 g kg^{-1}) > Alamo switchgrass planted in 1992 (9 g kg^{-1}) > Alamo planted in 1997 (6 g kg^{-1}) = the wheat-peanut rotation (5 g kg^{-1}) (Fig. 32a). Alamo planted in 1992 had 80% more SOC than the wheat-peanut rotation. Findings were similar to those in March where the wheat-peanut rotation had lower SOC than Alamo switchgrass planted in 1992. Soil organic C under bermudagrass at 0-5 cm had a significant increase from 14 to 17 g kg^{-1} from March to December. This increase may be due to above ground biomass and bermudagrass roots during growth plus the application of dairy manure. Soil organic C did not change significantly from March to December under Alamo switchgrass planted in 1992 (11 to 9 g kg^{-1}), Alamo planted in 1997 (6 to 6 g kg^{-1}), and the wheat-peanut rotation (5 to 5 g kg^{-1}).

Total Nitrogen

Soil total N at Clinton did not show a significant *season x vegetational treatment* interaction ($p=0.3637$; df=3,72). Soil total N was greatest under bahiagrass (1084 mg kg^{-1}) followed by Alamo (989 mg kg^{-1}) and Caddo switchgrass (959 mg kg^{-1}), and was lowest under forest (872 mg kg^{-1}) (Fig. 28b). Soil total N under switchgrass treatments was not different than that under bahiagrass or forest.

Soil total N at Hope showed a significant *season x vegetational treatment* interaction (p=0.0098; df=3,68). At 0-5 cm, treatments were not significantly different, but at 5-15 cm, total N was greatest under Caddo (844 mg kg^{-1})

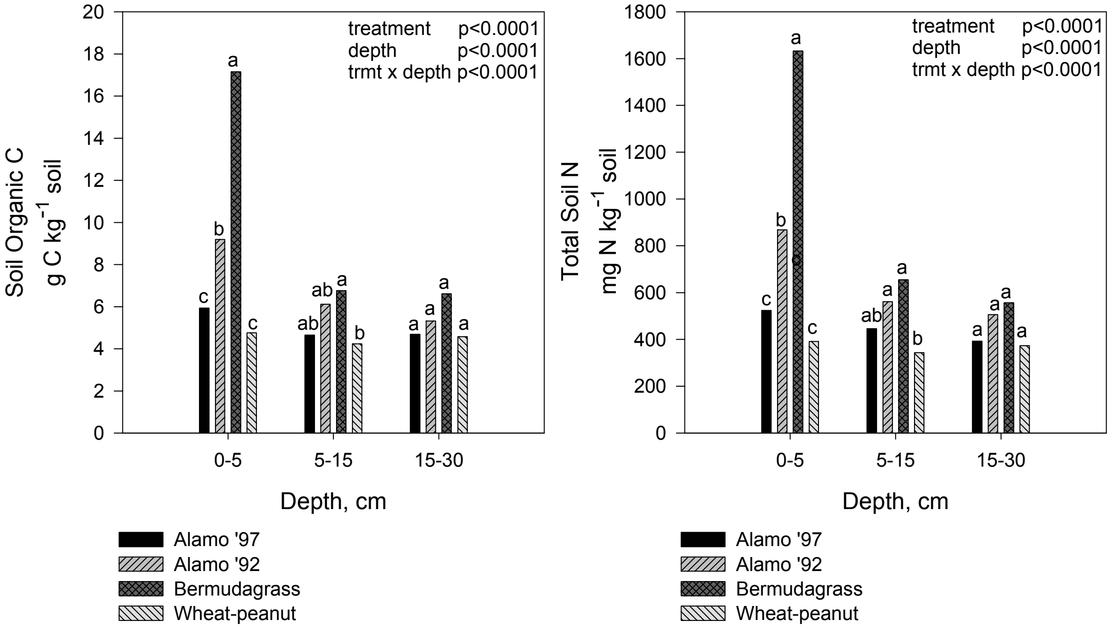
Figure 32a.

Figure 32b.

Figure 32. Effect of vegetational treatment and soil depth on a) soil organic C, and b) total N. Stephenville, TX, December 1999.

and Alamo switchgrass (840 mg kg^{-1}), and lowest under forest (589 mg kg^{-1}) and bahiagrass/fescue (563 mg kg^{-1}). At 15-30 cm, total N was in the order: forest (546 mg kg^{-1}) ≥ Alamo (488 mg kg^{-1}) > Caddo (445 mg kg^{-1}) > bahiagrass/fescue (417 mg kg^{-1}) (Fig. 29b). Total N under bahiagrass/fescue averaged across depth significantly decreased from 835 to 640 mg kg^{-1} from March to December. This N was probably mineralized and taken up by plants during the growing season. Soil organic C under bahiagrass/fescue also declined between sampling periods (Fig. 29a). The change in soil total N averaged across depth under Alamo (909 to 783 g kg^{-1}) and Caddo (733 to 714 g kg^{-1}) switchgrass, and forest (645 to 726 g kg^{-1}) was not significant.

Soil total N at Dallas also showed a significant *season x vegetational treatment* interaction (p=0.0032; df=3,72). At 0-5 cm, total N was greatest under bermudagrass (4846 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (2663 mg kg^{-1}) and 1997 (2500 mg kg^{-1}), and lowest under the wheat-cotton rotation (1533 mg kg^{-1}). Alamo switchgrass planted in 1992 and 1997 had 73 and 63% more soil total N than the wheat-cotton rotation. Similar trends were also observed at 5-15- and 15-30-cm depths (Fig. 30b). The results as in March were in accord with previous studies where organic N was lower in cultivated soils compared to soils where no disruption occurred (Franzluebbers et al., 1999, 2000). Total N under bermudagrass averaged across depth, as with SOC, significantly increased from 4093 to 4846 mg kg^{-1} from March to December. Nitrogen in biomass and roots and manure deposition from grazing cattle may have contributed to this result (Till and Kennedy, 1981). The change in soil total N averaged across depth under Alamo switchgrass planted in 1992 (2512 to 2633 g kg^{-1}) and 1997 (2282 to 2500 g kg^{-1}), and the wheat-cotton rotation (1504 to 1533 g kg^{-1}) was not significant.

At College Station, soil total N did not result in a significant *season x vegetational treatment* interaction (p=0.4324; df=3,72). At 0-5 cm, total N was greatest under Alamo switchgrass (1175 mg kg^{-1}) and kleingrass planted in 1992 (1128 mg kg^{-1}), followed by the sorghum-wheat-soybean rotation (928 mg kg^{-1}) and Alamo planted in 1997 (857 mg kg^{-1}) (Fig. 31b). During December, the sorghum-wheat-soybean rotation was not significantly different from Alamo switchgrass planted in 1992 and 1997 and kleingrass planted in 1992, possibly due to the use of high-residue crops and soybean, and their subsequent incorporation. No significant differences were noted at 5-15- and 15-30-cm depths.

Soil total N at Stephenville showed a significant *season x vegetational treatment x depth* interaction (p=0.0017; df=6,71). Soil total N at 0-5 cm was greatest under bermudagrass (1633 mg kg^{-1}) > Alamo switchgrass planted in

1992 (868 mg kg^{-1}) > Alamo planted in 1997 (523 mg kg^{-1}) = the wheat-peanut rotation (391 mg kg^{-1}) (Fig. 32b). Alamo planted in 1992 had 22% more soil total N than the wheat-peanut rotation. Total N under bermudagrass at 0-5 cm significantly increased from 1065 to 1633 mg kg^{-1} from March to December similar to reasons hypothesized for SOC increase. Changes at 0-5 cm under Alamo switchgrass planted in 1992 (757 to 868 g kg^{-1}) and 1997 (525 to 523 g kg^{-1}), and the wheat-peanut rotation (284 to 391 g kg^{-1}) were not significant. Changes with time also were not significant with depth.

Soil Microbial Biomass Carbon

Soil microbial biomass C at Clinton showed a significant *season x vegetational treatment* interaction (p<0.0001; df=3,72) Samples from 0-5 cm under bahiagrass showed the greatest value (1010 mg kg^{-1}) ≥ the forest (439 mg kg^{-1}) ≥ Alamo (419 mg kg^{-1}) ≥ Caddo switchgrass (370 mg kg^{-1}) (Fig. 33a). The bahiagrass pasture generally showed the highest values of all soil parameters evaluated, probably because of its longer establishment. Soil microbial biomass C under forest and switchgrass were not significantly different, similar to March findings. Soil microbial biomass C averaged across depth significantly changed from March to December under bahiagrass and Caddo switchghrass, increasing from 432 to 578 mg kg^{-1} under bahiagrass, and decreasing from 432 to 370 mg kg^{-1} under Caddo. The decrease under Caddo switchgrass may be due to less substrate available for the microbial population. Averaged across depth, the changes under Alamo (418 to 419 g kg^{-1}) and forest (386 to 439 g kg^{-1}) were not significant.

Soil microbial biomass C at Hope showed a significant *season x vegetational treatment x depth* interaction (p=0.0310; df=6,68). Averaged across depth, SMBC was greatest under bahiagrass/fescue (363 mg kg^{-1}) = forest

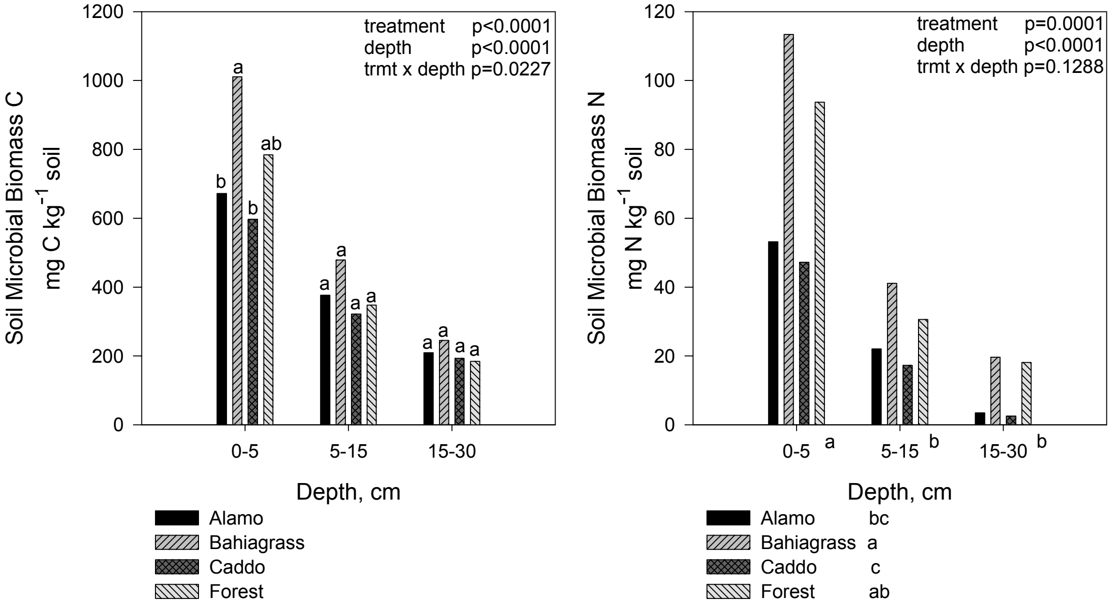

Figure 33a.

Figure 33b.

Figure 33. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Clinton, LA, December 1999.

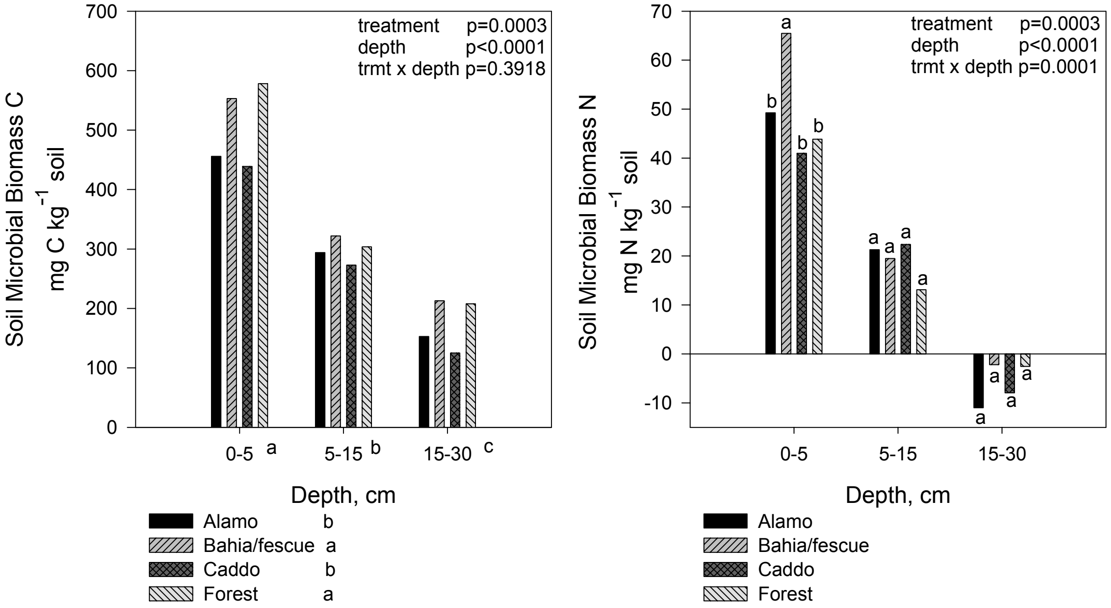

Figure 34a.

Figure 34b.

Figure 34. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Hope, AR, December 1999.

(363 mg kg^{-1}) > Alamo (301 mg kg^{-1}) = Caddo switchgrass (279 mg kg^{-1}) (Fig. 34a), following the same trend as in March. Soil microbial biomass C at 0-5 cm under bahiagrass/fescue decreased significantly from 777 to 553 mg kg^{-1} from March to December. Soil organic C under bahiagrass/fescue also decreased at this depth, and may help explain the decrease in SMBC (less substrate available for microbial population). Changes at 0-5 cm under Alamo (311 to 301 g kg^{-1}) and Caddo switchgrass (286 to 279 g kg^{-1}), and forest (365 to 363 g kg^{-1}) were not significant. Differences over time also were not seen at deeper depth.

Soil microbial biomass C at Dallas showed a significant *season x vegetational treatment* interaction (p=0.0177; df=3,72). Soil microbial biomass C in 0-5 cm was greatest under bermudagrass (2288 mg kg^{-1}) > Alamo switchgrass planted in 1992 (1246 mg kg^{-1}) = Alamo planted in 1997 (1092 mg kg^{-1}) > wheat-cotton rotation (627 mg kg^{-1}) (Fig. 35a). Similar results were noted at 5-15 and 15-30 cm. Similar to findings in March, the cultivated treatment also had the lowest SMBC value in December (Hu et al., 1997; Salinas-Garcia et al., 1997). Alamo switchgrass planted in 1992 and 1997 had 99 and 74% more SMBC than the wheat-cotton rotation. Soil microbial biomas C averaged across depth significantly decreased under the wheat-cotton rotation from 642 to 509 mg kg^{-1} from March to December, probably because of depletion of substrate due to rapid residue decomposition in this soil. The changes in SMBC averaged across depth under Alamo switchgrass planted in 1992 (938 to 888 g kg^{-1}) and 1997 (899 to 829 g kg^{-1}), and bermudagrass (1449 to 1456 g kg^{-1}) were not significant.

Soil microbial biomass C at College Station showed a significant *season x vegetational treatment x depth* interaction (p=0.0017; df=6,72). Soil microbial biomass C in samples from 0-5 cm were greatest under Alamo switchgrass planted in 1992 (963 mg kg^{-1}) > kleingrass planted in 1992 (714 mg kg^{-1}) = sorghum-wheat-soybean rotation (628 mg kg^{-1}) > Alamo planted in 1997 (487 mg kg^{-1}) (Fig. 36a).

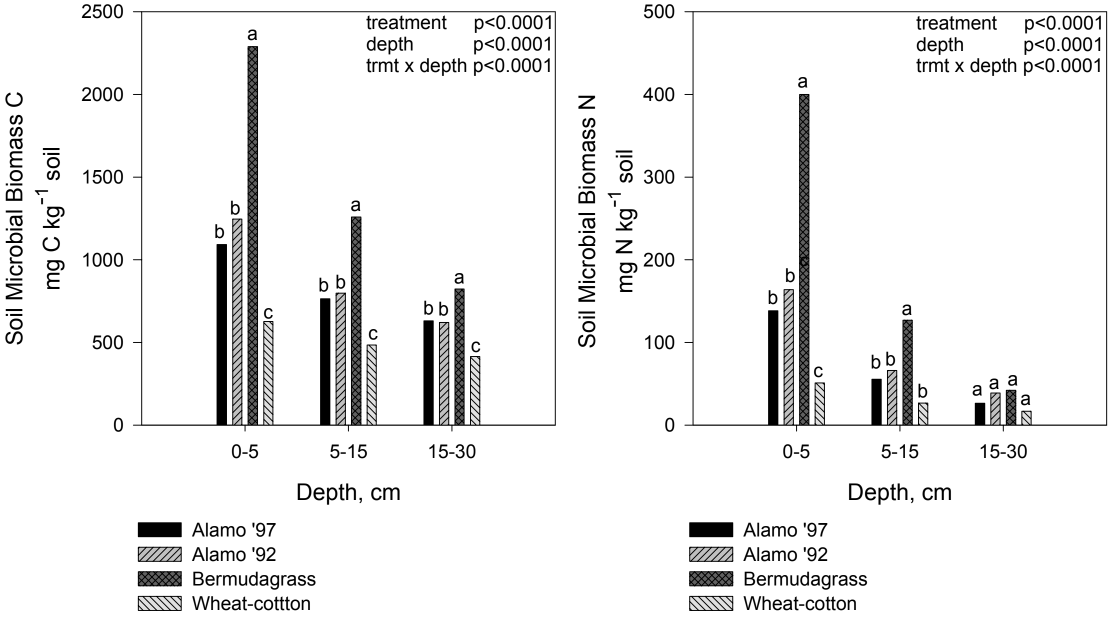
Figure 35a.

Figure 35b.

Figure 35. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Dallas, TX, December 1999.

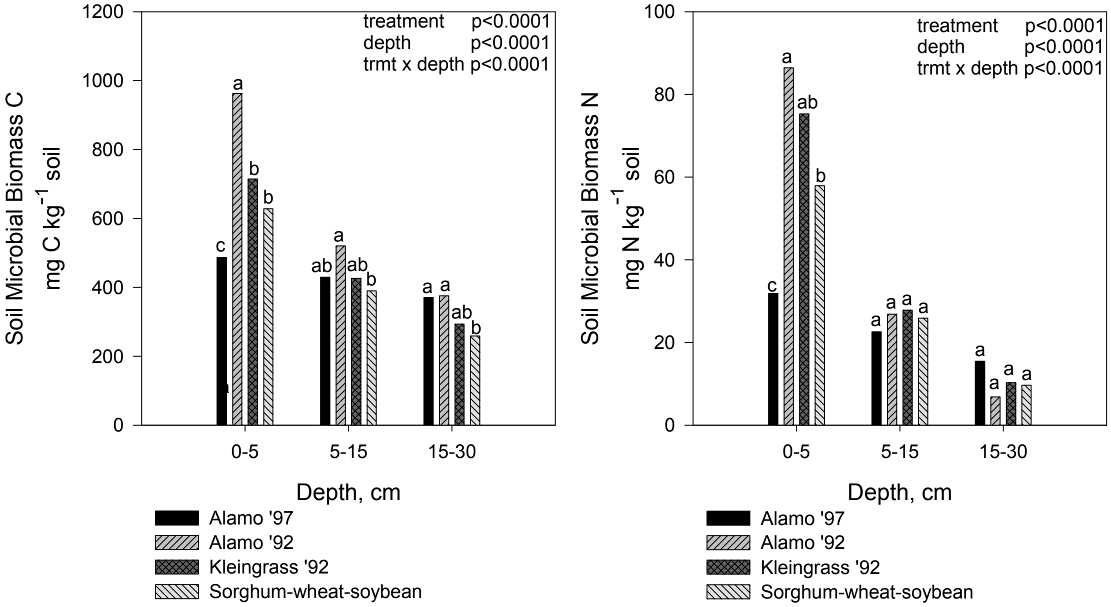
Figure 36a.

Figure 36b.

Figure 36. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. College Station, TX, December 1999.

Alamo switchgrass planted in 1992 had 53% more SMBC than the sorghum-wheat-soybean rotation, suggesting that the microbial population is negatively affected by tillage even when using high-cropping intensities, probably because of a faster depletion of substrate by exposure to microbes through incorporation. The sorghum-wheat-soybean rotation had 29% more SMBC than Alamo planted in 1997. The low value of SMBC under Alamo switchgrass planted in 1997 is probably due to its recent establishment and should increase with time. Soil microbial biomass C at 0-5 cm significantly increased under Alamo switchgrass planted in 1992 and the sorghum-wheat-soybean rotation from 757 to 963 mg kg^{-1} and 459 to 628 mg kg^{-1}, respectively, from March to December. The increase under Alamo planted in 1992 was probably due to a longer time of establishment and a more easily decomposable substrate, and it also suggests that Alamo residues may be of better quality than kleingrass. Under the sorghum-wheat-soybean rotation, the increase was probably due to two high residue crops and soybean, but the increase may just be temporary. Changes at 0-5 cm under Alamo switchgrass planted in 1997 (348 to 429 g kg^{-1}) and kleingrass planted in 1992 (563 to 478 g kg^{-1}) were not significant. Differences over time also were not observed at deeper depth.

Soil microbial biomass C at Stephenville showed a significant *season x vegetational treatment* interaction (p=0.0271; df=3,71). Soil microbial biomass C at 0-5 cm was greatest under bermudagrass (1117 mg kg^{-1}) > Alamo switchgrass planted in 1992 (509 mg kg^{-1}) = Alamo switchgrass planted in 1997 (497 mg kg^{-1}) > wheat-peanut rotation (372 mg kg^{-1}) (Fig. 37a). Bermudagrass as expected had the highest SMBC value. Alamo switchgrass planted in 1992 and 1997 had 37 and 34% more SMBC than the wheat-peanut rotation, which had the lowest SMBC, similar to March findings. There was a significant decrease of SMBC when averaged across depth from March to December under bermudagrass (1464 to 1117 mg kg^{-1}), Alamo planted in 1992 (728 to 509 mg kg^{-1}) and 1997 (761 to 497 mg kg^{-1}), and the wheat-peanut rotation (420 to 372 mg kg^{-1}). The decline may be related to temperature and dormancy of grasses since SOC and total N increased from March to December.

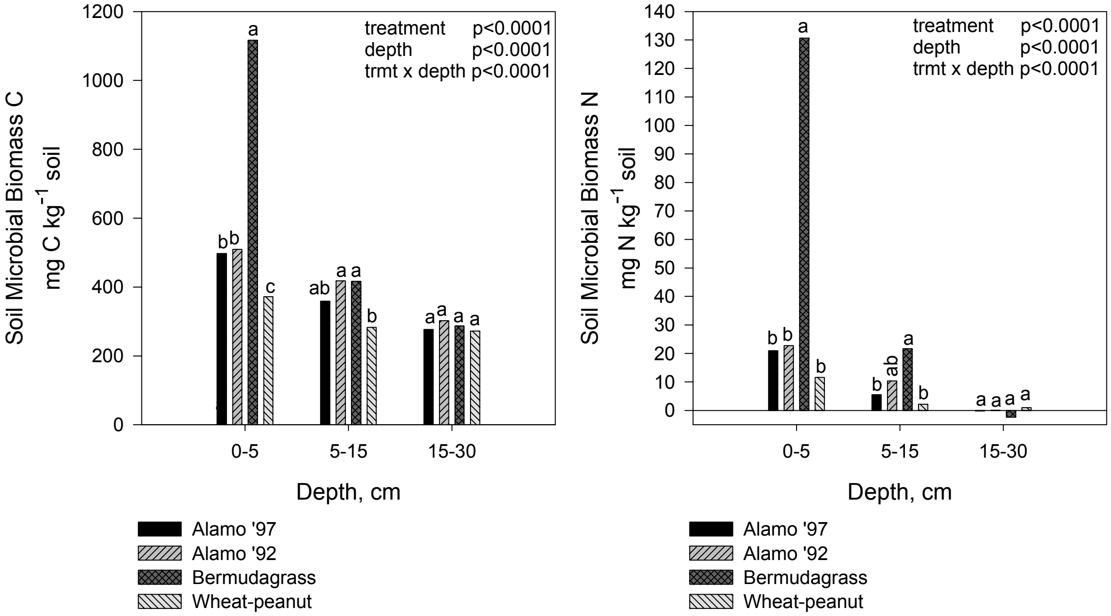
Figure 37a.

Figure 37b.

Figure 37. Effect of vegetational treatment and soil depth on a) soil microbial biomass C, and b) soil microbial biomass N. Stephenville, TX, December 1999.

Soil Microbial Biomass Nitrogen

Soil microbial biomass N at Clinton showed a significant *season x vegetational treatment* interaction (p=0.0118; df=3,72). Soil microbial biomass N averaged across depth was greatest under bahiagrass (58 mg kg^{-1}), followed by forest (47 mg kg^{-1}), and was lowest under Alamo (26 mg kg^{-1}) and Caddo (22 mg kg^{-1}) switchgrass (Fig. 33b). Forest and Alamo switchgrass were not significantly different. There was a significant increase of SMBN averaged across depth under bahiagrass and forest, increasing from 25 to 58 mg kg^{-1} and 10 to 47 mg kg^{-1}, respectively, from March to December. Soil microbial biomass C under bahiagrass also increased significantly over time. Microbial biomass C for forest also increased from March to December, though not significantly.

Changes in SMBN averaged across depth under Alamo (11 to 26 mg kg^{-1}) and Caddo (8 to 22 mg kg^{-1}) switchgrass were not significant.

Soil microbial biomass N at Hope showed a significant *season x vegetational treatment x depth* interaction ($p<0.0001$; df=6,68). Soil microbial biomass N at 0-5 cm was greatest under bahiagrass/fescue (65 mg kg^{-1}) > Alamo (49 mg kg^{-1}) = forest (44 mg kg^{-1}) = Caddo (41 mg kg^{-1}) switchgrass (Fig. 34b). No significant differences were found at 5-15 and 15-30 cm. Soil microbial biomass N under Alamo switchgrass and forest changed significantly from March to December, increasing under Alamo at 0-5 cm from 28 to 49 mg N kg^{-1}, and decreasing at 0-5 and 5-15 cm under forest from 113 to 44 and 50 to 13 mg kg^{-1}, respectively. The increase under Alamo may suggest a better quality substrate, and the decrease under forest may be related to tree species and lower quality of residue. Changes in SMBN at 0-5 cm under Caddo switchgrass (31 to 41 mg kg^{-1}) and bahiagrass/fescue (79 to 65 mg kg^{-1}) were not significant. Changes over time also were not different at deeper depth.

Soil microbial biomass N at Dallas did not show a significant *season x vegetational treatment* interaction ($p=0.1603$; df=3,72). At 0-5 cm, SMBN was greatest under bermudagrass (400 mg kg^{-1}) > Alamo switchgrass planted in 1992 (164 mg kg^{-1}) = Alamo planted in 1997 (138 mg kg^{-1}) > the wheat-cotton rotation (51 mg kg^{-1}) (Fig. 35b). Similar differences occurred at 5-15 cm, and no differences were found at 15-30 cm. Alamo switchgrass planted in 1992 and 1997 had 3.2 and 2.7 times more SMBN than the cultivated rotation. Differences were similar to those seen in March, and were in accord with previous studies (Franzluebbers, et al., 1994a,b, 1995a,b, 1998; Salinas-Garcia et al., 1997) that have shown that SMBC and SMBN decrease with tillage.

Soil microbial biomass N at College Station exhibited a significant *season x vegetational treatment x depth* interaction ($p=0.0008$; df=6, 72). At 0-5 cm, SMBN was greatest under Alamo switchgrass (86 mg kg^{-1}) and kleingrass planted in 1992 (75 mg kg^{-1}), followed by the sorghum-wheat-soybean rotation

(58 mg kg^{-1}), and was lowest under Alamo planted in 1997 (32 mg kg^{-1}) (Fig. 36b). No significant differences were seen at 5-15- and 15-30-cm depths. Alamo planted in 1992 had 48% more SMBN than the sorghum-wheat-soybean rotation, and this rotation had 81% more SMBN than Alamo planted in 1997. The low value under Alamo switchgrass planted in 1997 is probably due to its recent establishment. There was a significant temporal change in SMBN under the sorghum-wheat-soybean rotation at 0-5 cm, increasing from 39 to 58 mg kg^{-1} from March to December, probably because of the two high residue crops used, sorghum and wheat, and soybean, and subsequent residue incorporation. Changes in SMBN at 0-5 cm under Alamo switchgrass planted in 1992 (69 to 86 mg kg^{-1}) and 1997 (20 to 32 mg kg^{-1}), and kleingrass planted in 1992 (90 to 75 mg kg^{-1}) were not significant. Differences over time also were not observed at deeper depth.

Soil microbial biomass N at Stephenville did not show a significant *season x vegetational treatment* interaction for SMBN (p=0.1769; df=3,71). At 0-5 cm, SMBN was greatest under bermudagrass (131 mg kg^{-1}) > Alamo switchgrass planted in 1992 (23 mg kg^{-1}) = Alamo planted in 1997 (21 mg kg^{-1}) = the wheat-peanut rotation (12 mg kg^{-1}) (Fig. 37b). Similar effects were noted at 5-15 cm, and no significant differences were found at 15-30 cm. The SMBN concentration under the wheat-peanut rotation was not significantly different than that under switchgrass treatments, possibly because the rotation includes peanut which is a legume, and also because there is cattle grazing of wheat. These two factors may provide more N to the microbial population in this treatment.

Carbon Mineralization

Carbon mineralized in 24 days at Clinton showed a significant *season x vegetational treatment* interaction (p=0.0466; df=3,72). Carbon mineralized at 0-5 cm was greatest under bahiagrass (616 mg kg^{-1}) > forest (472 mg kg^{-1}) = Alamo (398 mg kg^{-1}) = Caddo (370 mg kg^{-1}) switchgrass (Fig. 38a). Similar differences were seen at 5-15 cm, while no differences were observed at 15-30 cm. The higher value under bahiagrass is expected because of its longer establishment. Mineralizable C under forest and switchgrass were not significantly different, suggesting the presence of more labile forms of C under switchgrass than forest at this location. Mineralizable C followed similar trends as those of SMBC. Carbon mineralized in 24 days averaged across depth significantly increased from March to December under bahiagrass (285 to 358 mg kg^{-1}), and Alamo (167 to 250 mg kg^{-1}) and Caddo switchgrass (164 to 217 mg kg^{-1}), suggesting an increase in more labile forms of C from grasses with time at this location. The change in mineralizable C over time under forest (246 to 273 mg kg^{-1}) was not significant.

At Hope, C mineralization showed a significant *season x vegetational treatment* interaction (p<0.0001; df=3,68). Averaged across depth, mineralizable C was greatest under Alamo switchgrass (221 mg kg^{-1}) > bahiagrass/fescue (178 mg kg^{-1}) = forest (176 mg kg^{-1}) = Caddo (173 mg kg^{-1}) (Fig. 39a). Alamo mineralized more soil C from December samples than forest, contrary to March when results were the opposite. During December, forest samples had more SMBC than Alamo, although Alamo mineralized more C, suggesting that Alamo may provide more labile forms of C than forest. Mineralizable C averaged across depth significantly changed under Alamo switchgrass and bahiagrass/fescue from March to December, increasing under Alamo from 145 to 221 mg kg^{-1} and decreasing under bahiagrass/fescue from 209 to 178 mg kg^{-1}.

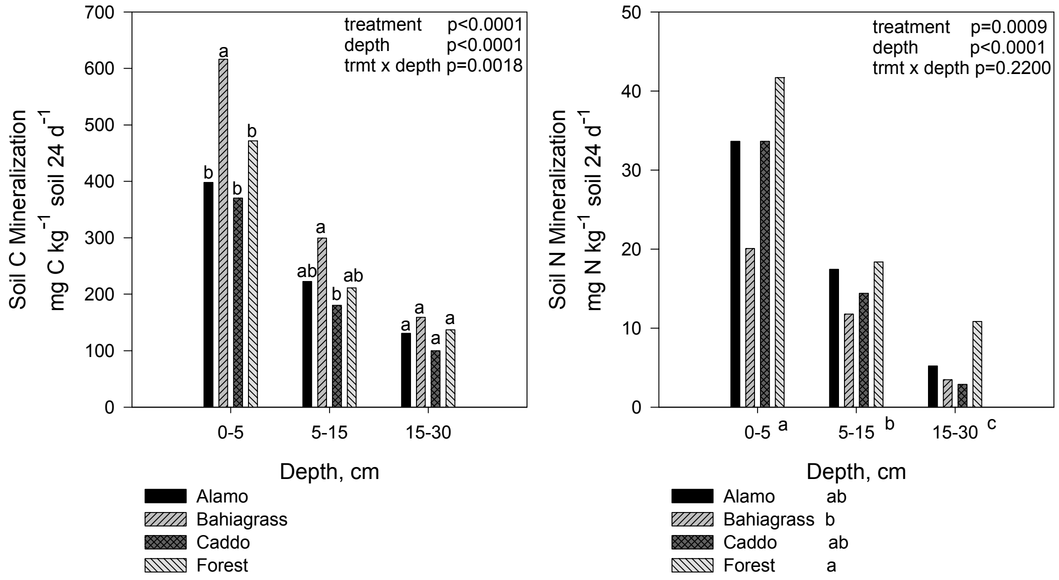
Figure 38a.

Figure 38b.

Figure 38. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Clinton, LA, December 1999.

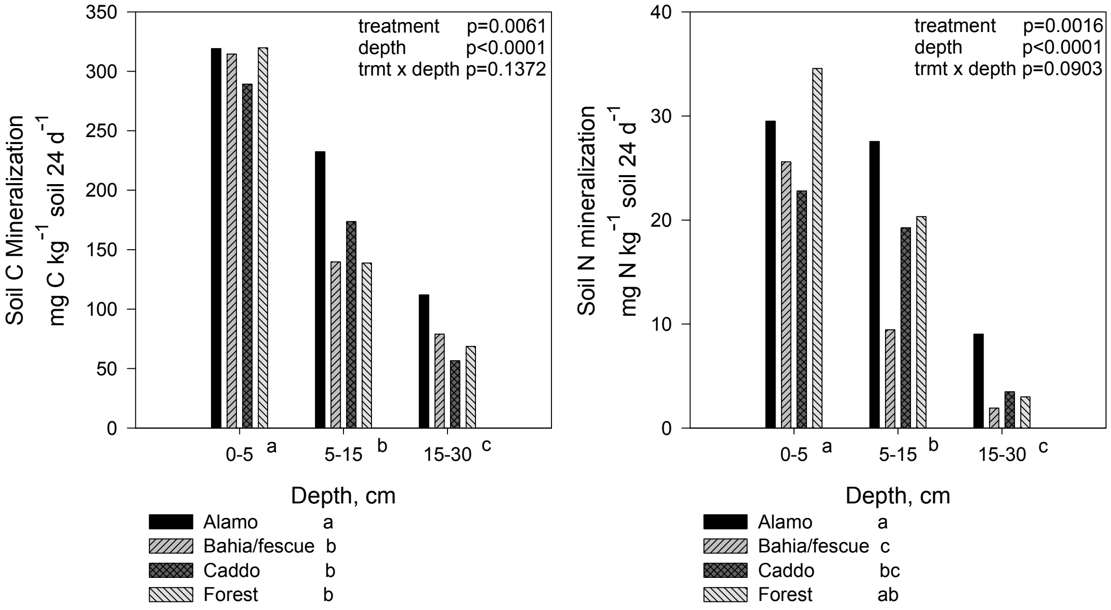
Figure 39a.

Figure 39b.

Figure 39. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Hope, AR, December 1999.

The increase under Alamo was probably due to availability of more labile forms of C with time, and the decrease in mineralizable C under bahiagrass/fescue was probably due to depletion of substrate, which also probably caused the decrease in SMBC under this treatment at this location. Averaged across depth, changes under Caddo switchgrass (144 to 173 mg kg^{-1}) and forest (186 to 176 mg kg^{-1}) were not significant.

At Dallas, C mineralization showed a significant *season x vegetational treatment x depth* interaction (p=0.0044; df=6,72). Mineralized C at 0-5 cm was greatest under bermudagrass (875 mg kg^{-1}) > Alamo switchgrass planted in 1992 (435 mg kg^{-1}) > Alamo planted in 1997 (340 mg kg^{-1}) > the wheat-cotton rotation (244 mg kg^{-1}). Similar differences were also observed at 5-15- and 15-30-cm depths (Fig. 40a). Alamo switchgrass planted in 1992 and 1997 mineralized 78 and 39% more C than the wheat-cotton rotation. Trends were similar to those seen in March, and to that of previous studies (Franzluebbers et al., 1994a,b, 1995a,b, 1998, 2000; Salinas-garcia et al., 1997). Mineralizable C at 0-5 cm significantly increased under bermudagrass from 728 to 875 mg kg^{-1} from March to December, probably because of this grass' longer time of establishment and the deposition of manure by cattle. Changes at 0-5 cm under Alamo planted in 1992 (373 to 435 mg kg^{-1}) and 1997 (283 to 340 mg kg^{-1}), and the wheat-cotton rotation (219 to 244 mg kg^{-1}) were not significant. Temporal changes also were not observed at deeper depth.

At College Station, C mineralization showed a significant *season x vegetational treatment x depth* interaction (p<0.0001; df=6,72). Mineralized C at 0-5 cm was greatest under Alamo switchgrass planted in 1992 (393 mg kg^{-1}) = the sorghum-wheat-soybean rotation (384 mg kg^{-1}) = kleingrass planted in 1992 (339 mg kg^{-1}) > Alamo planted in 1997 (229 mg kg^{-1}) (Fig. 41a). No significant differences were noted at 5-15 and 15-30 cm.

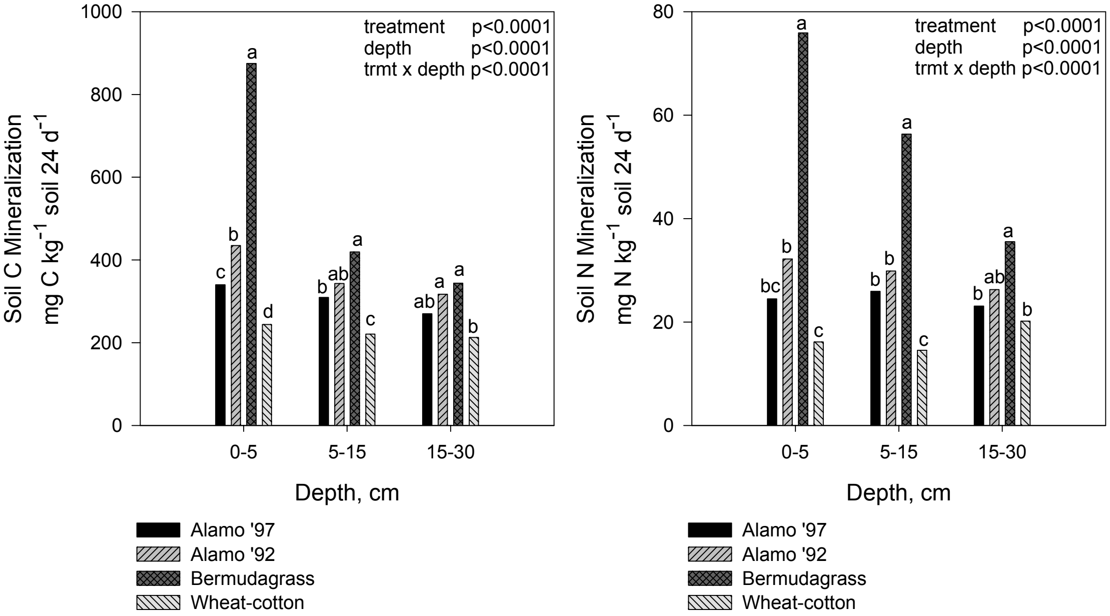

Figure 40a.

Figure 40b.

Figure 40. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Dallas, TX, December 1999.

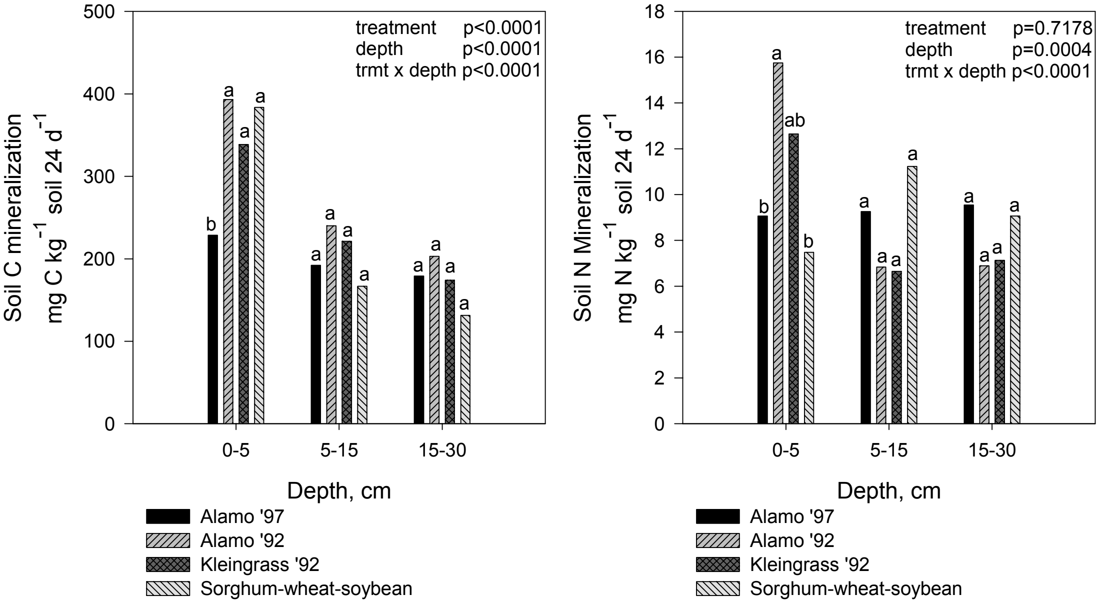

Figure 41a.

Figure 41b.

Figure 41. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. College Station, TX, December 1999.

Contrary to March findings, the sorghum-wheat-soybean rotation was not significantly different from Alamo and kleingrass planted in 1992, possibly because of high-residue crops in the rotation with subsequent incorporation of residues that made substrate more available to the microbial population. Mineralizable C at 0-5 cm significantly increased under Alamo switchgrass planted in 1992 and the sorghum-wheat-soybean rotation, from 298 to 393, and 156 to 384 mg kg^{-1}, respectively, from March to December. The increase under Alamo was probably due to longer time of establishment and may also indicate that Alamo switchgrass residues are of higher quality than kleingrass residues. The increase under the sorghum-wheat-soybean rotation may be due to greater exposure of residues to the microbial population through incorporation. Changes at 0-5 cm under Alamo planted in 1997 (155 to 229 mg kg^{-1}), and kleingrass planted in 1992 (348 to 339 mg kg^{-1}) were not significant. Temporal changes were not observed at deeper depth.

At Stephenville, soil C mineralization did not exhibit a significant *season x vegetational treatment* interaction (p=0.1673; df=3,71). At 0-5 cm, mineralized C was greatest under bermudagrass (593 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (309 mg kg^{-1}) and 1997 (298 mg kg^{-1}), and was lowest under the wheat-peanut rotation (209 mg kg^{-1}) (Fig. 42a). Alamo planted in 1992 had 48% more mineralizable C than the wheat-peanut rotation.

Nitrogen Mineralization

Nitrogen mineralized in 24 days at Clinton did not have a significant *season x vegetational treatment* interaction (p=0.3419; df=3,72). Averaged across depth, mineralized N was greatest under forest (24 mg kg^{-1}), followed by Alamo (19 mg kg^{-1}) and Caddo (17 mg kg^{-1}) switchgrass, and was lowest under bahiagrass (12 mg kg^{-1}) (Fig. 38b).

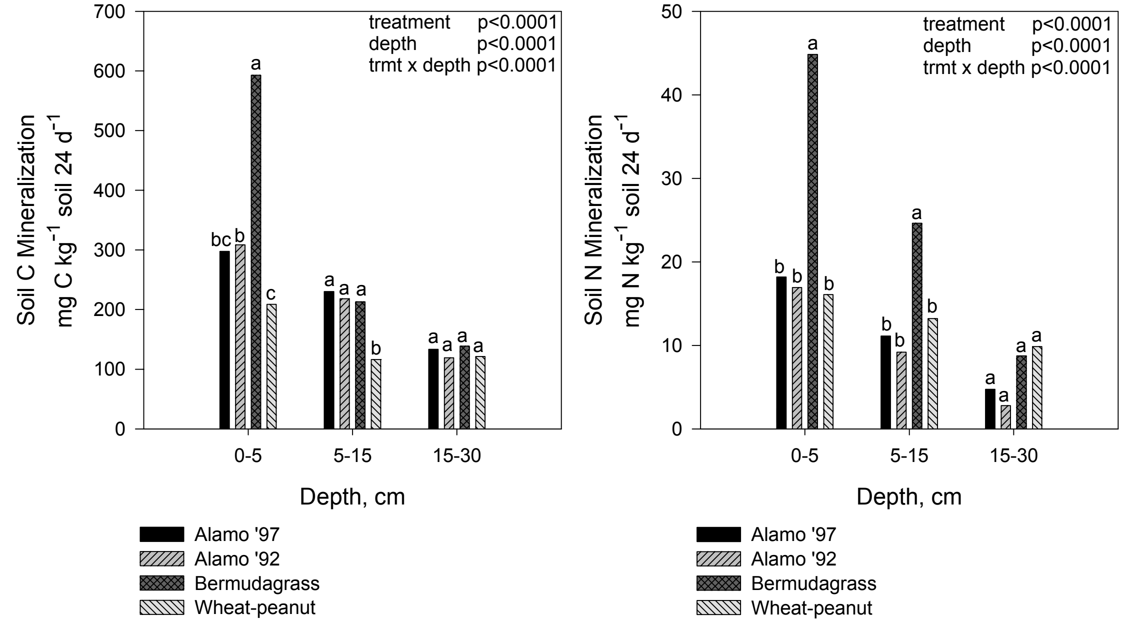

Figure 42a. Figure 42b.

Figure 42. Effect of vegetational treatment and soil depth on a) mineralizable C, and b) mineralizable N. Stephenville, TX, December 1999.

Mineralizable N under forest and switchgrass treatments was not significantly different, nor were switchgrass treatments different from bahiagrass.

At Hope, N mineralization showed a significant *season x vegetational treatment* interaction (p=0.0003; df=3,68). Averaged across depth, mineralized N was greatest under Alamo switchgrass (22 mg kg^{-1}) and forest (19 mg kg^{-1}), followed by bahiagrass/fescue (15 mg kg^{-1}), and was lowest under Caddo (12 mg kg^{-1}) (Fig. 39b). Mineralizable N averaged across depth significantly changed under Alamo, increasing from 12 to 22 mg kg^{-1} from March to December. Changes averaged across depth under bahiagrass/fescue (16 to 12 mg kg^{-1}), Caddo switchgrass (17 to 15 mg kg^{-1}), and forest (13 to 19 mg kg^{-1}) were not significant.

Mineralizable N at Dallas showed a significant *season x vegetational treatment x depth* interaction (p<0.0001;df=6,72). At 0-5 cm, mineralized N was greatest under bermudagrass (76 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (32 mg kg^{-1}) and 1997 (24 mg kg^{-1}), and was lowest under the wheat-cotton rotation (17 mg kg^{-1}) (Fig. 40b). Similar differences were also observed at 5-15 and 15-30 cm. Alamo switchgrass planted in 1992 (0-5 cm) mineralized 88% more N than the wheat-cotton rotation, similar to findings in March. Mineralizable N under bermudagrass at 0-5 cm, however, significantly decreased from 116 to 76 mg kg^{-1} from March to December, possibly because of N immobilization. Changes at 0-5 cm under Alamo switchgrass planted in 1992 (39 to 32 mg kg^{-1}) and 1997 (34 to 24 mg kg^{-1}), and the wheat-cotton rotation (22 to 16 mg kg^{-1}) were not significant. Temporal changes were not noted at deeper depth.

At College Station, N mineralization showed a significant *season x vegetational treatment x depth* interaction (p=0.0004; df=6,72). At 0-5 cm, mineralized N was greatest under Alamo switchgrass (16 mg kg^{-1}) and kleingrass planted in 1992 (13 mg kg^{-1}), followed by Alamo planted in 1997 (9 mg kg^{-1}) and the sorghum-wheat-soybean rotation (7 mg kg^{-1}) (Fig. 41b). Alamo planted in 1992 mineralized 2.3 times more N than the sorghum-wheat-soybean rotation. Mineralizable N under the sorghum-wheat-soybean rotation was possibly taken up by plants or incorporated into microbial biomass (SMBN significantly increased under this treatment from March to December). No significant differences were found at deeper depth.

Mineralizable N at Stephenville had a significant *season x vegetational treatment* interaction (p<0.0001; df=3,71). Mineralized N at 0-5 cm was greatest under bermudagrass (45 mg kg^{-1}) > Alamo switchgrass planted in 1997 (18 mg kg^{-1}) = Alamo planted in 1992 (17 mg kg^{-1}) = the wheat-peanut rotation (16 mg kg^{-1}). Similar differences were seen at 5-15 cm, with no significant differences at 15-30 cm (Fig. 42b). Mineralizable N under wheat-peanut was not significantly different than Alamo switchgrass planted in 1992 and in 1997, probably because of residue incorporation and the use of peanut, a legume. Mineralizable N averaged across depth significantly increased under bermudagrass from 17 to 26 mg kg^{-1} from March to December, probably because of the longer time of establishment and the application of dairy manure. Changes averaged across depth under Alamo switchgrass planted in 1992 (14 to 10 mg kg^{-1}) and 1997 (11 to 11 mg kg^{-1}), and the wheat-peanut rotation (10 to 13 mg kg^{-1}) were not significant.

Basal Soil Respiration

Basal soil respiration at Clinton did not exhibit a significant *season x vegetational treatment* interaction (p=0.1941; df=3,72). At 0-5 cm, BSR was greatest under bahiagrass (220 mg kg^{-1}) > forest (162 mg kg^{-1}) > Alamo (119 mg kg^{-1}) = Caddo (110 mg kg^{-1}) switchgrass (Fig. 43a). No significant differences were observed at deeper depth. The difference between forest and switchgrass might be attributed to the higher C input under forest and the recent establishment of switchgrass.

Basal soil respiration at Hope showed a significant *season x vegetational treatment x depth* interaction (p<0.0259; df=6,68). Basal soil respiration was not significantly different among the vegetational treatments for December samples (Fig. 44a), contrary to March findings. Basal soil respiration at 0-5 cm, however, significantly decreased under bahiagrass/fescue from 150 to 109 mg kg^{-1} from March to December, following the pattern of SMBC and mineralizable C which also decreased under this treatment at this location. Changes at 0-5 cm under Alamo (78 to 103 mg kg^{-1}) and Caddo (101 to 76 mg kg^{-1}) switchgrass, and forest (120 to 98 mg kg^{-1}) were not significant. Significant temporal effects were not seen at deeper depth.

Basal soil respiration at Dallas showed a significant *season x vegetational treatment x depth* interaction (p=0.0059; df=6,72). At 0-5 cm, BSR was greatest under bermudagrass (283 mg kg^{-1}) > Alamo switchgrass planted in 1992 (145 mg kg^{-1}) > Alamo planted in 1997 (110 mg kg^{-1}) > the wheat-cotton rotation (80 mg kg^{-1}) (Fig. 45*a*). Similar differences were also noted at deeper depths. Alamo planted in 1992 and 1997 had 81 and 38% greater BSR than the wheat-cotton rotation. Basal soil respiration at 0-5 cm significantly increased under bermudagrass from 223 to 283 mg kg^{-1} from March to December. Changes at 0-5 cm under Alamo planted in 1992 (118 to 145 mg kg^{-1}) and 1997 (87 to 110 mg kg^{-1}), and the wheat-cotton rotation (63 to 80 mg kg^{-1}) were not significant. Temporal effects were not observed at deeper depth.

Basal soil respiration at College Station showed a significant *season x vegetational treatment x depth* interaction (p<0.0001; df=6,72). At 0-5 cm, BSR was greatest under the sorghum-wheat-soybean rotation (143 mg kg^{-1}) and Alamo switchgrass planted in 1992 (132 mg kg^{-1}), followed by kleingrass planted in 1992 (108 mg kg^{-1}), and was lowest under Alamo planted in 1997 (73 mg kg^{-1}) (Fig. 46a). No significant differences were noted at deeper depth. Basal soil respiration at 0-5 cm significantly increased under Alamo planted in 1992 and the sorghum-wheat-soybean rotation from 85 to 132 and 44 to 143 mg kg^{-1}, respectively, from March to December. Both treatments also had a significant increase in SMBC and mineralizable C, so the increase in BSR should be expected. Changes at 0-5 cm under Alamo switchgrass planted in 1997 (49 to 73 mg kg^{-1}) and kleingrass planted in 1992 (105 to 108 mg kg^{-1}) were not significant. Temporal effects were not noted at deeper depth.

Basal soil respiration at Stephenville showed a significant *season x vegetational treatment x depth* interaction (p=0.0130; df=6,71). At 0-5 cm, BSR was greatest under bermudagrass (114 mg kg^{-1}), followed by Alamo switchgrass planted in 1992 (113 mg kg^{-1}) and 1997 (110 mg kg^{-1}), and was lowest under the wheat-peanut rotation (77 mg kg^{-1}) (Fig. 47a). No significant differences were seen at deeper depth. Basal soil respiration under Alamo switchgrass planted in 1992 was 47% greater than under the wheat-peanut rotation.

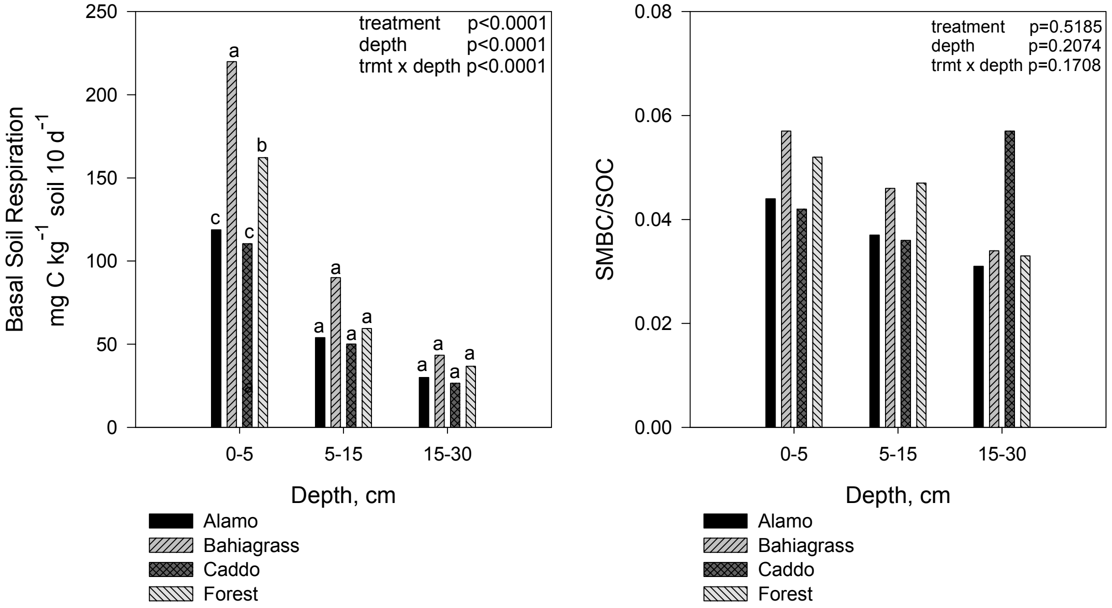
Figure 43a.

Figure 43b.

Figure 43. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Clinton, LA, December 1999.

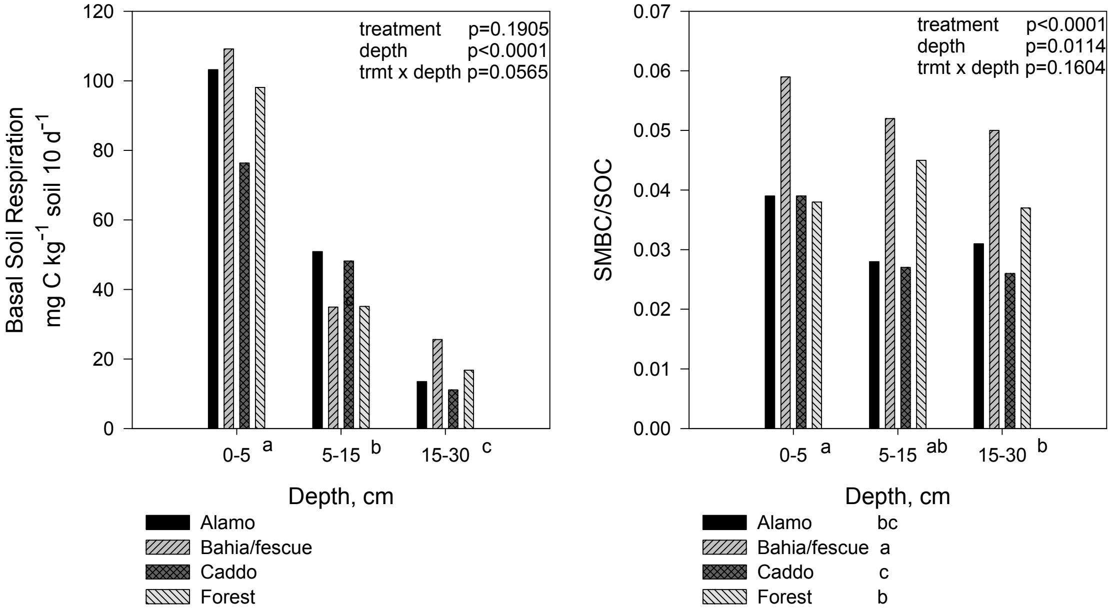
Figure 44a.

Figure 44b.

Figure 44. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Hope, AR, December 1999.

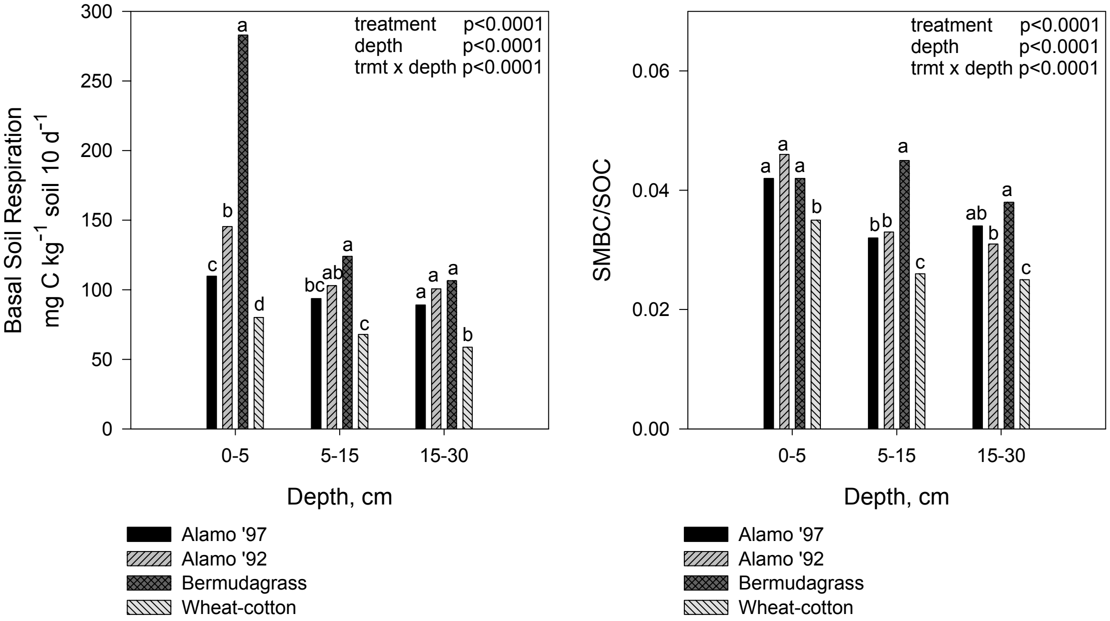

Figure 45a.

Figure 45b.

Figure 45. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Dallas, TX, December 1999.

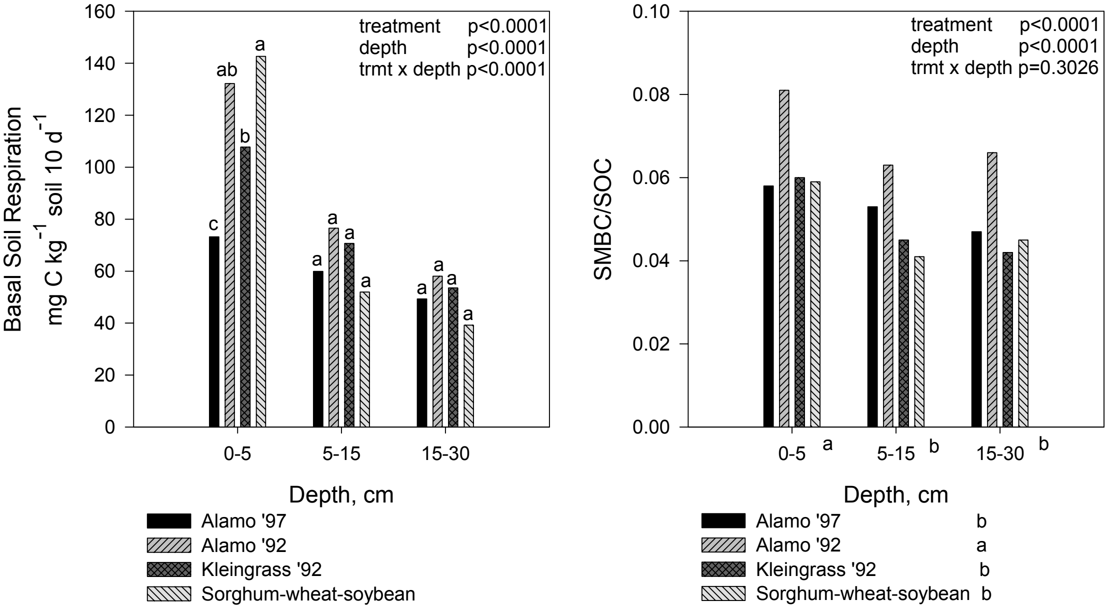

Figure 46a.

Figure 46b.

Figure 46. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. College Station, TX, December 1999.

Basal soil respiration at 0-5 cm significantly increased under bermudagrass, Alamo planted in 1997, and the wheat-peanut rotation from 148 to 220, 68 to 110, and 24 to 77 mg kg^{-1}, respectively, from March to December. It is not clear why these increases happened because SMBC decreased under all treatments, and there was not a significant increase in mineralizable C, except for the wheat-peanut rotation. BSR did not significantly change under Alamo planted in 1992 (90 to 113 mg kg^{-1}).

Ratio of Soil Microbial Biomass Carbon:Soil Organic Carbon

The ratio SMBC/SOC at Clinton showed a significant *season x vegetational treatment* interaction (p=0.0006; df=3,72). The ratio of SMBC/SOC during December was not affected by the different vegetational treatments or depth, averaging 0.043 (43b). These results were contrary to those from March where there were significant differences among treatments.

At Hope, SMBC/SOC showed a significant *season x vegetational treatment* interaction (p=0.0001; df=3,68). Averaged across depth, SMBC/SOC was greatest under bahiagrass/fescue (0.054), followed by forest (0.040), and was lowest under Alamo (0.033) and Caddo (0.032) switchgrass (Fig. 44b). SMBC/SOC averaged across depth significantly decreased under forest from 0.053 to 0.040 from March to December. This decrease may indicate the more recalcitrant nature of forest organic matter. Changes averaged across depth under Alamo (0.037 to 0.033), Caddo (0.038 to 0.032), and bahiagrass/fescue (0.049 to 0.054) were not significant.

SMBC/SOC at Dallas showed a significant *season x vegetational treatment x depth* interaction (p<0.0001; df=6,72). SMBC/SOC at 0-5 cm was in the order: Alamo switchgrass planted in 1992 (0.046) = Alamo planted in 1997 (0.043) = bermudagrass (0.042) > the wheat-cotton rotation (0.036) (Fig. 45b). At 5-15 cm, the order was bermudagrass > Alamo planted in 1992 = Alamo planted in

1997 > the wheat cotton rotation. Similar effects were seen at 15-30 cm. The wheat-cotton rotation showed the lowest SMBC/SOC ratio at all depths. SMBC/SOC at 0-5 cm significantly decreased under bermudagrass from 0.073 to 0.042 from March to December. Changes at 0-5 cm under Alamo switchgrass planted in 1992 (0.045 to 0.046) and 1997 (0.045 to 0.043), and the wheat-cotton rotation (0.044 to 0.036) were not significant. Temporal changes were not observed at deeper depth.

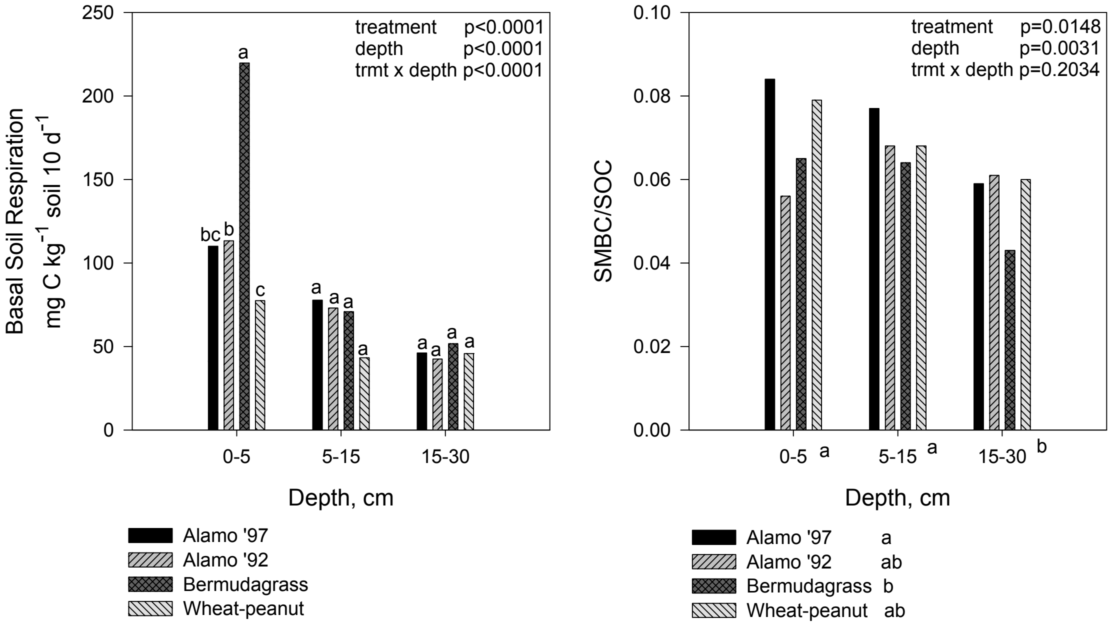
Figure 47a.

Figure 47b.

Figure 47. Effect of vegetational treatment and soil depth on a) basal soil respiration, and b) ratio of SMBC/SOC. Stephenville, TX, December 1999.

At College Station, SMBC/SOC showed a significant *season x vegetational treatment* interaction (p<0.0001; df=3,72). Averaged across depth, SMBC/SOC was greatest under Alamo switchgrass planted in 1992 (0.070) > Alamo planted in 1997 (0.053) = kleingrass planted in 1992 (0.050) = the sorghum-wheat-soybean rotation (0.049) (Fig. 46b). Similar to March findings, permanent vegetative cover with no soil disturbance over the long-term apparently increases SMBC/SOC ratio at this location. SMBC/SOC averaged across depth significantly decreased under kleingrass planted in 1992 from 0.065 to 0.050 from March to December. Changes averaged across depth under Alamo planted in 1992 (0.061 to 0.070) and 1997 (0.047 to 0.053), and the sorghum-wheat-soybean rotation (0.049 to 0.049) were not significant.

At Stephenville, SMBC/SOC showed a significant *season x vegetational treatment* interaction ($p<0.0141$; df=3,71). Averaged across depth, SMBC/SOC was greatest under Alamo switchgrass planted in 1997 (0.074), followed by the wheat-peanut rotation (0.069) and Alamo planted in 1992 (0.062), and was lowest for bermudagrass (0.058) (Fig. 47b). At this location, SMBC/SOC under wheat-peanut was not significantly different from switchgrass, probably because of residue incorporation, making substrate more available for microbial degradation, but this effect may be temporary. Detrimental effects of cultivation have been well documented (Hass et al., 1957; Mann, 1986; Franzluebbers et al., 1998). SMBC/SOC averaged across depth decreased significantly under Alamo switchgrass planted in 1997 and bermudagrass from 0.099 to 0.074, and 0.096 to 0.058, respectively, from March to December. Changes averaged across depth under Alamo planted in 1992 (0.070 to 0.062), and the wheat-peanut rotation (0.087 to 0.069) were not significant.

CHAPTER V

CONCLUSIONS

1. Soil organic C varied with location, cropping treatment, depth, and season. Soil organic C in general was greatest under long-term bermudagrass pasture, second highest under Alamo switchgrass and kleingrass planted in 1992 and forest, followed by switchgrass planted in 1997, and was lowest under the cultivated soils.
2. Soil organic C at 0-5 cm was 42-220% greater in soils under Alamo switchgrass planted in 1992 than in cultivated soils, except at College Station where the SOC values under Alamo planted in 1992 and the cultivated rotation were not significantly different. Although the rotation treatment is cultivated at this location, two high-residue crops (grain sorghum and wheat) are used. In general, these results suggest that cultivation is detrimental to SOC (Hass et al., 1957; Mann, 1986; Franzluebbers et al., 1998). Residue incorporation, disruption of soil aggregates, and increased aeration will promote loss of SOM (Balesdent et al., 1990).
3. Similar trends as those of SOC were noted for soil total N, microbial biomass C and N, mineralizable C and N, BSR, and the ratio of SMBC/SOC.
4. Total N at 0-5 cm was 22-270% greater under Alamo switchgrass planted in 1992 than under cultivated soils. For the December sampling at College Station, soil total N under Alamo planted in 1992 was not significantly different than under the sorghum-wheat-soybean rotation, possibly due to the use of high-residue crops and soybean.
5. Soil microbial biomass C at 0-5 cm was 51-99% greater under Alamo switchgrass planted in 1992 than under cultivated soils. Soil microbial

biomass N followed a similar trend, and was 48-320% greater under Alamo planted in 1992 than under cultivated soils, except at Stephenville where SMBN under swtichgrass and the cultivated soil was not significantly different, possibly because the rotation includes peanut which is a legume, and also because there is cattle grazing of wheat. These two factors may provide more N to the microbial population in this treatment.

6. Mineralizable C at 0-5 cm was 48-330% greater under Alamo switchgrass planted in 1992 than in cultivated soils. During December sampling, C mineralization under Alamo planted in 1992 and the sorghum-wheat-soybean rotation was not significantly different, possibly because of high residue crops in the rotation with subsequent incorporation of residues. Mineralizable N generally followed a similar trend, and was 77-230% greater under Alamo planted in 1992 than in cultivated soils.
7. Basal soil respiration generally followed a similar trend as that of mineralizable C at 0-5 cm and was 47-375% greater under Alamo switchgrass planted in 1992 than in cultivated soils.
8. The SMBC/SOC ratio averaged across depth at College Station was significantly greater for Alamo switchgrass planted in 1992 than the sorghum-wheat-soybean rotation during March and December sampling. During December at Dallas, SMBC/SOC at 0-5 cm was significantly greater under Alamo planted in 1992 than under the wheat-cotton rotation, but they were not different during March, possibly because incorporation of residues increased the SMBC during this time in the cultivated soil. For the March sampling at Stephenville, Alamo switchgrass planted in 1997 had greater SMBC/SOC than the wheat-peanut rotation, although they were not significantly different. Similar results were found for December. Cattle grazing of wheat as well as

residue incorporation may have increased the microbial population in the cultivated treatment.

9. Insufficient information was collected in this study to determine whether the values of parameters evaluated for forest and switchgrass were different.
10. In addition to its high yield potential, adaptation to marginal sites, and tolerance to water and nutrient limitations, switchgrass appeared to be a competitive crop in terms of land sustainability, resulting in enhanced soil quality characteristics compared to long-term cultivated soils.

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APPENDIX A

ANALYSES OF VARIANCE

Analyses of Variance Clinton, LA, March 1999

Table A-1. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	918.3770	83.4888	29.1354
Error	36	103.1595	2.8655	Prob > F
C. Total	47	1021.5366		<.0001

Table A-2. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	6708890.2	609899	15.6720
Error	36	1400989.8	38916	Prob > F
C. Total	47	8109880.0		<.0001

Table A-3. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2324774.8	211343	39.2639
Error	36	193774.7	5383	Prob > F
C. Total	47	2518549.4		<.0001

Table A-4. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	10073.792	915.799	13.4480
Error	36	2451.582	68.099	Prob > F
C. Total	47	12525.374		<.0001

Table A-5. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	726738.06	66067.1	92.1138
Error	36	25819.14	717.2	Prob > F
C. Total	47	752557.20		<.0001

Table A-6. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	13658.180	1241.65	11.9679
Error	36	3734.937	103.75	Prob > F
C. Total	47	17393.117		<.0001

Table A-7. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	74971.710	6815.61	56.8417
Error	36	4316.580	119.90	Prob > F
C. Total	47	79288.290		<.0001

Table A-8. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00619639	0.000563	12.6874
Error	36	0.00159837	0.000044	Prob > F
C. Total	47	0.00779476		<.0001

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Table A-9. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	791.26008	71.9327	25.7725
Error	36	100.47820	2.7911	Prob > F
C. Total	47	891.73828		<.0001

Table A-10. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	5925281.1	538662	18.3600
Error	36	1056202.4	29339	Prob > F
C. Total	47	6981483.5		<.0001

Table A-11. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	3066034.3	278730	27.9529
Error	36	358972.0	9971	Prob > F
C. Total	47	3425006.3		<.0001

Table A-12. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	52099.580	4736.33	12.5089
Error	36	13630.908	378.64	Prob > F
C. Total	47	65730.488		<.0001

Table A-13. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	1118936.2	101721	52.1334
Error	36	70242.3	1951	Prob > F
C. Total	47	1189178.5		<.0001

Table A-14. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	7041.6905	640.154	15.1766
Error	36	1518.4883	42.180	Prob > F
C. Total	47	8560.1788		<.0001

Table A-15. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	157089.84	14280.9	53.5808
Error	36	9595.08	266.5	Prob > F
C. Total	47	166684.92		<.0001

Table A-16. Effect of vegetational treatment and soil depth the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00367491	0.000334	1.3909
Error	36	0.00864711	0.000240	Prob > F
C. Total	47	0.01232202		0.2193

Analyses of Variance Hope, AR, March 1999

Table A-17. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	498.16993	45.2882	32.5511
Error	32	44.52147	1.3913	Prob > F
C. Total	43	542.69140		<.0001

Table A-18. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2819679.6	256335	9.5915
Error	32	855204.8	26725	Prob > F
C. Total	43	3674884.4		<.0001

Table A-19. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	1625878.2	147807	148.8970
Error	32	31765.8	993	Prob > F
C. Total	43	1657644.0		<.0001

Table A-20. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	48404.807	4400.44	61.6271
Error	32	2284.935	71.40	Prob > F
C. Total	43	50689.742		<.0001

Table A-21. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	638915.24	58083.2	88.1475
Error	32	21085.82	658.9	Prob > F
C. Total	43	660001.06		<.0001

Table A-22. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	3329.3219	302.666	14.0317
Error	32	690.2452	21.570	Prob > F
C. Total	43	4019.5671		<.0001

Table A-23. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	66047.062	6004.28	37.1986
Error	32	5165.160	161.41	Prob > F
C. Total	43	71212.222		<.0001

Table A-24. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00420806	0.000383	11.5829
Error	32	0.00105687	0.000033	Prob > F
C. Total	43	0.00526493		<.0001

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Table A-25. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	490.11324	44.5557	39.6498
Error	36	40.45439	1.1237	Prob > F
C. Total	47	530.56764		<.0001

Table A-26. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2335776.2	212343	14.4240
Error	36	529975.3	14722	Prob > F
C. Total	47	2865751.5		<.0001

Table A-27. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	984711.7	89519.2	32.4468
Error	36	99322.3	2759.0	Prob > F
C. Total	47	1084034.0		<.0001

Table A-28. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	26894.823	2444.98	81.4327
Error	36	1080.885	30.02	Prob > F
C. Total	47	27975.708		<.0001

Table A-29. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	467565.85	42506.0	32.8251
Error	36	46617.23	1294.9	Prob > F
C. Total	47	514183.08		<.0001

Table A-30. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	5700.7643	518.251	14.4869
Error	36	1287.8600	35.774	Prob > F
C. Total	47	6988.6243		<.0001

Table A-31. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	57393.450	5217.59	26.2546
Error	36	7154.280	198.73	Prob > F
C. Total	47	64547.730		<.0001

Table A-32. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00489029	0.000445	8.5649
Error	36	0.00186862	0.000052	Prob > F
C. Total	47	0.00675891		<.0001

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Table A-33. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	771.98685	70.1806	49.9236
Error	36	50.60739	1.4058	Prob > F
C. Total	47	822.59424		<.0001

Table A-34. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	23769024	2160820	50.9304
Error	36	1527371	42427	Prob > F
C. Total	47	25296395		<.0001

Table A-35. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	8785561.5	798687	113.3424
Error	36	253680.5	7047	Prob > F
C. Total	47	9039242.0		<.0001

Table A-36. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	344031.48	31275.6	81.8048
Error	36	13763.52	382.3	Prob > F
C. Total	47	357795.00		<.0001

Table A-37. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	935081.97	85007.5	89.8668
Error	36	34053.37	945.9	Prob > F
C. Total	47	969135.34		<.0001

Table A-38. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	32189.890	2926.35	100.6694
Error	36	1046.482	29.07	Prob > F
C. Total	47	33236.372		<.0001

Table A-39. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	89507.391	8137.04	36.5017
Error	36	8025.187	222.92	Prob > F
C. Total	47	97532.578		<.0001

Table A-40. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00567812	0.000516	42.2004
Error	36	0.00044035	0.000012	Prob > F
C. Total	47	0.00611847		<.0001

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Table A-41. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	4598.0870	418.008	105.8733
Error	36	142.1348	3.948	Prob > F
C. Total	47	4740.2219		<.0001

Table A-42. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	38786153	3526014	105.6742
Error	36	1201206	33367	Prob > F
C. Total	47	39987360		<.0001

Table A-43. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	11500602	1045509	250.2950
Error	36	150376	4177	Prob > F
C. Total	47	11650978		<.0001

Table A-44. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	504952.41	45904.8	122.5649
Error	36	13483.23	374.5	Prob > F
C. Total	47	518435.64		<.0001

Table A-45. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	1367136.9	124285	119.6206
Error	36	37403.8	1039	Prob > F
C. Total	47	1404540.7		<.0001

Table A-46. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	13745.980	1249.63	70.4623
Error	36	638.453	17.73	Prob > F
C. Total	47	14384.433		<.0001

Table A-47. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	149472.28	13588.4	115.3927
Error	36	4239.28	117.8	Prob > F
C. Total	47	153711.56		<.0001

Table A-48. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00204398	0.000186	35.6905
Error	36	0.00018743	0.000005	Prob > F
C. Total	47	0.00223141		<.0001

Analyses of Variance College Station, TX, March 1999

Table A-49. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	182.64888	16.6044	16.5735
Error	36	36.06727	1.0019	Prob > F
C. Total	47	218.71616		<.0001

Table A-50. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2154486.8	195862	16.2698
Error	36	433383.7	12038	Prob > F
C. Total	47	2587870.6		<.0001

Table A-51. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	1380575.9	125507	30.2889
Error	36	149171.9	4144	Prob > F
C. Total	47	1529747.8		<.0001

Table A-52. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	30795.207	2799.56	90.5409
Error	36	1113.135	30.92	Prob > F
C. Total	47	31908.342		<.0001

Table A-53. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	221206.39	20109.7	39.6644
Error	36	18251.86	507.0	Prob > F
C. Total	47	239458.24		<.0001

Table A-54. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	243.13131	22.1028	1.2043
Error	36	660.69755	18.3527	Prob > F
C. Total	47	903.82886		0.3192

Table A-55. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	21824.526	1984.05	32.5004
Error	36	2197.688	61.05	Prob > F
C. Total	47	24022.213		<.0001

Table A-56. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00333774	0.000303	3.8271
Error	36	0.00285423	0.000079	Prob > F
C. Total	47	0.00619197		0.0011

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Table A-57. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	178.24615	16.2042	15.1183
Error	36	45.09787	1.2527	Prob > F
C. Total	47	223.34402		<.0001

Table A-58. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2124349.4	193123	15.1183
Error	36	423085.0	11752	Prob > F
C. Total	47	2547434.4		<.0001

Table A-59. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	1724071.6	156734	15.1183
Error	36	69511.5	1931	Prob > F
C. Total	47	1793583.1		<.0001

Table A-60. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	30170.801	2742.80	15.1183
Error	36	1945.840	54.05	Prob > F
C. Total	47	32116.641		<.0001

Table A-61. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	332373.01	30215.7	15.1183
Error	36	43992.95	1222.0	Prob > F
C. Total	47	376365.95		<.0001

Table A-62. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	334.44287	30.4039	15.1183
Error	36	168.30102	4.6750	Prob > F
C. Total	47	502.74389		<.0001

Table A-63. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	49717.882	4519.81	15.1183
Error	36	5457.330	151.59	Prob > F
C. Total	47	55175.212		<.0001

Table A-64. Effect of vegetational treatment and soil depth on SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00623523	0.000567	15.1183
Error	36	0.00146667	0.000041	Prob > F
C. Total	47	0.00770190		<.0001

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Table A-65. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	281.72138	25.6110	31.6673
Error	35	28.30633	0.8088	Prob > F
C. Total	46	310.02772		<.0001

Table A-66. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2082190.4	189290	22.4303
Error	35	295366.7	8439	Prob > F
C. Total	46	2377557.1		<.0001

Table A-67. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	3685483.6	335044	22.0201
Error	35	532538.2	15215	Prob > F
C. Total	46	4218021.8		<.0001

Table A-68. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	30936.313	2812.39	27.8925
Error	35	3529.040	100.83	Prob > F
C. Total	46	34465.353		<.0001

Table A-69. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	588077.95	53461.6	71.4077
Error	35	26203.84	748.7	Prob > F
C. Total	46	614281.79		<.0001

Table A-70. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2773.2896	252.117	15.8002
Error	35	558.4807	15.957	Prob > F
C. Total	46	3331.7703		<.0001

Table A-71. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	50445.735	4585.98	43.6820
Error	35	3674.490	104.99	Prob > F
C. Total	46	54120.225		<.0001

Table A-72. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.01268583	0.001153	2.9836
Error	35	0.01352845	0.000387	Prob > F
C. Total	46	0.02621428		0.0068

Analyses of Variance Stephenville, TX, December 1999

Table A-73. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	562.91005	51.1736	40.5036
Error	36	37.21447	1.0337	Prob > F
C. Total	47	600.12452		<.0001

Table A-74. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	5546299.8	504209	68.5849
Error	36	264657.6	7352	Prob > F
C. Total	47	5810957.4		<.0001

Table A-75. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2391210.9	217383	126.9703
Error	36	61634.7	1712	Prob > F
C. Total	47	2452845.7		<.0001

Table A-76. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	58391.446	5308.31	220.9167
Error	36	865.029	24.03	Prob > F
C. Total	47	59256.475		<.0001

Table A-77. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	790908.50	71900.8	51.8470
Error	36	49924.35	1386.8	Prob > F
C. Total	47	840832.85		<.0001

Table A-78. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	5478.5933	498.054	31.9565
Error	36	561.0734	15.585	Prob > F
C. Total	47	6039.6667		<.0001

Table A-79. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	110256.38	10023.3	48.3068
Error	36	7469.73	207.5	Prob > F
C. Total	47	117726.11		<.0001

Table A-80. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00546822	0.000497	3.1547
Error	36	0.00567277	0.000158	Prob > F
C. Total	47	0.01114099		0.0045

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Table A-81. Effect of vegetational treatment and soil depth on SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	156.40067	14.2182	15.1183
Error	36	33.85678	0.9405	Prob > F
C. Total	47	190.25745		<.0001

Table A-82. Effect of vegetational treatment and soil depth on total N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	738294.80	67117.7	13.6848
Error	36	176563.21	4904.5	Prob > F
C. Total	47	914858.00		<.0001

Table A-83. Effect of vegetational treatment and soil depth on SMBC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	196860.68	17896.4	16.6301
Error	36	38741.23	1076.1	Prob > F
C. Total	47	235601.90		<.0001

Table A-84. Effect of vegetational treatment and soil depth on SMBN

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	6147.2766	558.843	35.1730
Error	36	571.9830	15.888	Prob > F
C. Total	47	6719.2596		<.0001

Table A-85. Effect of vegetational treatment and soil depth on mineralizable C

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	172079.44	15643.6	40.5805
Error	36	13877.81	385.5	Prob > F
C. Total	47	185957.25		<.0001

Table A-86. Effect of vegetational treatment and soil depth on mineralizable N

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	888.3100	80.7555	16.3562
Error	36	177.7424	4.9373	Prob > F
C. Total	47	1066.0524		<.0001

Table A-87. Effect of vegetational treatment and soil depth on BSR

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	17310.300	1573.66	28.1338
Error	36	2013.660	55.94	Prob > F
C. Total	47	19323.960		<.0001

Table A-88. Effect of vegetational treatment and soil depth on the ratio of SMBC/SOC

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.01170360	0.001064	2.4360
Error	36	0.01572331	0.000437	Prob > F
C. Total	47	0.02742690		0.0218

VITA

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