Utilization of Forest Slash to Sequester Carbon in Loblolly Pine Plantations in the Lower Coastal Plain

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Introduction

Significant areas of forest soils in the South are inherently carbon and nutrient poor and have been further degraded by land use practices. Many of these sites have been converted to pine plantations. Clearcutting is the most economical and efficient method of harvesting these stands, but the harvesting and subsequent site preparation may have negative consequences for soil properties especially on the soil and soil organic matter (SOM) pool. Restoring degraded soil and enhancing inherently poor soil can lead to increased productivity and carbon sequestration in forest systems. An effective means of increasing and stabilizing SOM is through the application of organic soil amendments (Buford et al. 1999, Sanchez et al. 2000), and forest biomass in the form of logging residues is usually a readily available source.

Objectives

The broad objectives of this study include using mulching and tilling to incorporate forest biomass into the soil to: (1) increase the nutrient pool, (2) improve soil physical properties, and (3) increase carbon sinks. The focus is on determining the impact of this practice on the carbon storage patterns, greenhouse gas fluxes, water quality and off-site movement, soil chemical and physical properties, and short- and long-term productivity of the system. Application of findings from this study are important in developing opportunities for managing soil carbon pools, and restoring degraded forest soils.

Approach

Different mulching and tillage treatments for incorporating forest slash into soils during site preparation prior to replanting were examined as a means of increasing the soil carbon and nutrient pool. The mulching/tillage treatments were compared with conventional and control treatments that did not involve surface application or incorporation of forest slash into the soil. A Rayco Model T275 Hydra-Stumper was used to install the study. The machine was equipped with a 2.4 m horizontal rotating drum with 36 attached swing hammers that mulched logging slash, stumps, and humus layer that remained in the soil surface or was incorporated to approximately 20 cm thereby mixing the woody biomass into the soil. The conventional operation included one pass of a dozer with a KG V-blade to shear stumps and roll logging debris to the sides to clear the strip for bedding. Another dozer was used on the second pass to apply fertilizer and to bed with a disk bedding plow.

Project Description

The study was installed in October 1997 to compare mulching and tilling with conventional site preparation techniques in two sites: a wet pine flat with a sandy loam horizon over a clay horizon (mineral site) and a pocosin site with deep organic soil (organic site). The study sites are located in the Lower Coastal Plain region of eastern North Carolina. The area receives approximately 1346 mm of annual precipitation with 55% of the total received between April and September. Air temperatures range between 2 - 30 °C with an average winter temperature of 8 °C and an average summer temperature of 25 °C. The stands were loblolly pine (*Pinus taeda* L.) plantations that had been clearcut and replanted with the same species. Mulched slash and stumps as a treatment was compared to mulching and tilling into the soil as another treatment. Finally, a comparison was made between mulching strips and broadcast mulching.

The treatments differed by soil type. On the organic site, the treatments were:

- Control (CON): no mulching, no V shearing, no bedding, no fertilizer, no weed control

- Conventional (CVN): V shearing, bedding, fertilizer, weed control
- Strip mulch (SM): bedding, fertilizer, weed control
- Strip mulch/till (SMT): tilling, bedding, fertilizer, weed control

On the mineral site, the treatments were:

- Control (CON): no mulching, no V shearing, no bedding, no fertilizer, no weed control
- Conventional (CVN): V shearing, bedding, fertilizer, weed control
- Strip mulch (SM): bedding, fertilizer, weed control
- Strip mulch/till (SMT): tilling, bedding, fertilizer, weed control
- Broadcast mulch (BAB): bedding, fertilizer, weed controlBroadcast mulch (BNB): no bedding, fertilizer, weed controlThe plots were 40 x 40 m with a

measurement area of 20 X 20 m. The area was blocked based on logging traffic and micro-elevation and had 4 blocks per treatment in close proximity to ensure uniformity of residual slash, stump size and distribution, and soil.

A productivity time study was done for each treatment plot on each site (Sanchez et al. 2000). Mean travel speeds for each site/treatment combination were determined and used to adjust productivities as if the machine were operating on a square 8 ha tract. Costs were estimated using the machine rate method (Brinker 1989).

The relationship between tillage treatments and soil response was assessed through the measurement of soil strength and bulk density within measurement plots of each treatment area. A soil core apparatus, with an interior diameter of 6.7 cm, collected soil cores to a depth 0.5 m in three locations in each measurement plot. Each core was subdivided into 0.10 m increments, weighed in its field moist state, and oven dried to obtain dry soil weights for bulk density and quantitative water estimates. Soil strength data was collected by a Rimik CP20 recording cone penetrometer in 0.025 m increments to a depth of 0.5 m. Penetrometer measurements were taken in nine locations within each measurement plot and mean cone index values were reported as the average of all insertions per treatment within a depth range of 0.10 m. Soil samples and penetrometer measurements were conducted in all treatments but two locations in bedded treatments were evaluated: in bed and off bed locations.

Prior to treatment installation, soil samples were collected from the upper 15 cm of the soil with a 2.0 cm diameter soil corer from twenty random locations within each site. After treatment installation, additional soil samples were collected from five locations (four corner points and a central point) within each measurement area of each treatment plot. In treatment plots that included bedding, soil samples were collected from the bed and in the inter-bed regions, yielding five samples per plot collected on the bed and five samples per plot collected from the inter-bed. All of the inter-bed sampling points were adjacent to the five locations collected on-bed. The soil samples were analyzed for total C and N on a NA 1500 Carlo Erba C/N/S analyzer. The remaining samples were composited by block, treatment, location (bed or inter-bed), and site resulting in four samples for each treatment/location/site combination.

Results

Productivity Time Study

All mulching and tillage treatments were more expensive to implement than the conventional system (Sanchez et al. 2000). The cost per hectare for the strip mulch treatment on the mineral site ($216.94) was comparable to conventional costs estimated on the mineral site ($196.24). The cost per hectare of the conventional treatment on the organic site ($301.46) was higher due to the higher shearing cost per hectare ($172.63 versus $67.41 on the mineral site). The strip surface mulch treatment applied on the mineral site had the lowest cost per hectare. The highest cost per hectare occurred with the strip mulch/soil till treatment on the organic site ($470.71). Of the treatments tested, the strip mulch operating under conditions similar to that which existed on the mineral site has the most potential for implementation. To justify using this method over a conventional system, an added benefit in carbon credits and/or growth response would have to be realized.

Soil physical properties

On the mineral site, the implementation of each treatment resulted in a reduction in mean bulk density to a depth of 0.30 m compared to pretreatment levels (CON) with the exception of the surface layer of SMT, BAB and BNB and the immediate subsurface layer of BNB (figure 1A) (Sanchez et al. 2000). The greatest change in soil bulk density from the pretreatment condition occurred in the 0.10 - 0.20 m soil layer and coincided with the depth of incorporation of mulched material; this was evident in all treatments except BNB. The movement of machine traffic over the site in BNB increased soil compaction in the immediate subsoil layer as indicated by the elevated bulk density. Soil bulk density levels in the 0.20 - 0.30 m depth of each treatment remained slightly lower than CON and BNB but the primary benefit of lowering bulk density occurred in the 0.10 - 0.20 m depth range. A slight decline in bulk density was observed in the 0.40 - 0.50 m depth range compared to the overlying soil layers and may be indicative of the formation of a traffic pan at that depth. In general, mean bulk density increased with depth in each treatment and peaked in the 0.30 - 0.40 m depth in each treatment compared with CON and BNB, which peaked at shallower depths.

Bulk density was reduced in response to tillage treatments at all depths in the organic site with the exception of the upper 0.30 m of the SMT treatment, which was similar to bulk density values of CON (figure 1B). Mean bulk density increased with depth in all treatments and appeared to peak in value at the lowest soil depths (0.40 –0.50 cm). The results would indicate a reduction in bulk density in all layers of the soil profile within the organic site in response to CVN and SM treatments, but showed no additional benefit from tilling organic material into subsurface layers (SMT). The results of an analysis of variance indicated the main effect of treatment ($P < 0.15$) was not a significant source of variation for bulk density but depth ($P < 0.001$) and the interaction of depth and treatment ($P < 0.001$) were highly significant in the mineral site. Treatment ($P < 0.05$) and depth ($P < 0.001$) were significant factors in bulk density estimations in the organic sites.Cone index values within each treatment area of the mineral site were generally lowest in the soil surface layer (0.0 - 0.10 m) and increased with successive depths (figure 2A) (Sanchez et al. 2000). Reductions in cone index values in the upper 0.20 m from the pretreatment values (CON) were noted as a result of the implementation of each tillage treatment with the exception of BNB. Soil strength remained elevated at all depths in BNB compared to each treatment including CON. Soil strength reduction appeared to be limited to the upper 0.20 m soil layer of each treatment as mean cone index values differed only slightly from pretreatment levels (CON) below 0.20 m. The higher soil strength levels below 0.30 m in all treatments compared with CON may be the result of tillage impacts that extended to deeper portions of the soil profile. Peak soil strength levels were achieved in the deeper soil layers of each treatment and may be a reflection of the influence of higher bulk densities and lowered soil moisture contents on soil strength.

Mean cone index values within each treatment in the organic soil site were lower at each depth in comparison to the CON treatment (figure 2B). The implementation of each treatment in the organic site lowered mean cone index values from harvested levels, which remained consistent with depth. Mean cone index values were similar at all depths among the treatments under evaluation and only exceeded 1.0 MPa in the lowest depth (0.40 – 0.50 m) in SMT.

Soil carbon and nitrogen

On the mineral site, soil C and N increased on the mulching treatment plots for the first 2 years of the study, followed by a general decrease (figures 3A and 3B). There was an initial increase in C and N on the CVN treatments but did not vary significantly thereafter; whereas, the CON treatment had high variability and did not show significant change in C and N. Carbon dioxide efflux measurements were lower entering the second year (figure 4A), indicating that the decrease of soil C and N was probably not due to decomposition. A possible explanation is that the C and N are penetrating deeper into the soil. In the future, we will be doing deeper sampling to attempt to test this hypothesis.

On the organic site, soil C and N decreased for all treatments, except for an increase at 1.5 years (figures 5A and 5B). Additionally, the CO_2 efflux measurements were consistent with changes observed in the C and N pools (figure 4B).

Tree growth and survival

Survival was high on the mineral site (> 90%) and did not differ significantly between treatments although the non-bedded treatment plots (BNB and CON) had the lowest survival percentage (~ 85 – 87%). On the organic site, the mulching treatment plots had the highest survival percentage (SMT ~ 82%, SM ~ 78%), followed by the CVN treatment plots (72%) and the CON treatment plots had very low survival percentages (30%). On the mineral site, the CVN treatment had the best tree growth after the first year but the mulching treatments were advancing at a more rapid rate going into the second year (figure 6A). Bedding had a significant effect on tree growth with the non-bedded treatments (BNB and CON) having the lowest tree growth. On the organic site, tree growth was highest on the mulching treatment plots followed by the CVN and the CON plots (figure 6B).

Benefits

Presently SOM is not actively considered as part of the forest management prescription. Certainly, Best Management Practices are designed to protect the soil but opportunities for managing SOM to achieve long-term multiple resource objectives are not presently considered. The results obtained from this study will determine (1) if SOM can be affected by forest management practices, and (2) what management approaches could be developed to increase carbon sequestration in managed forests. Benefits from this project will be primarily realized in managing and improving forest conditions in the southern US, but insights gained into SOM processes will be useful in other regions too.

This study suggests that the incorporation of forest slash as a means to sequester carbon, increase soil nutrient levels, and improve soil physical properties is a realistic possibility. Comparison of the mineral and organic sites shows that the incorporation of forest slash does not always yield improved soil chemical and physical properties (e.g., the organic site), which raises the question as to which soil types would benefit from organic matter incorporation. Another area of this study is the development of carbon and nutrient budgets. This is currently being done with the collection of soil CO_2 efflux, soil nutrient, and soil water data. This study is still in its infancy and there remains the question of whether the observations will persist. Additionally, there is the question as to the availability of the sequestered carbon and the associated nutrients on different soil types. The answer to these and related questions will probably not be available for a few more years. Increased utilization of the Rayco T275 Hydra-Stumper (or similar machinery) for site preparation activities should lower costs associated with mulching and residue incorporation. Lower site preparation costs coupled with the potential increases in site productivity and the desire to collect carbon credits for sequestering carbon make the incorporation of forest slash a viable site preparation option.

Future Activities

This study will advance our understanding of the interactions of forest management practices and soil processes. Soil organic matter and nutrient content and relevant soil physical parameters in undisturbed and harvested soils will be measured annually to assess their subsequent response to incorporation of forest slash into surface and subsurface layers. Factors influencing SOM turnover including soil structure and quality, soil water holding capacity, nutrient dynamics, carbon dynamics, biomass production, the vegetative community, and water quality will also be measured.

A second study was installed in the winter of 2000 to examine the effects of deep incorporation (40 cm) of forest slash into upland soils of different textures (sandy and clay soils). Additionally, different slash loads were applied to examine the carbon sequestration potential of these soils. Specific hypotheses that will be tested in this study are:

1. Deep incorporation of forest slash into the soil will significantly increase long-term carbon storage in the soil and aboveground biomass.
2. Incorporating different levels of forest slash into the soil will result in significantly different levels of carbon storage.
3. Deep incorporation of forest slash will alter soil physical properties favoring accelerated SOM turnover.

The study is located within the Savannah River Site National Environmental Research Park (US Department of Energy - Savannah River Site) on Atlantic Upper Coastal Plain.

References

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Buford, M.A., B.J. Stokes, F.G. Sanchez, and E.A. Carter. 1999. Using biomass to improve site quality and carbon sequestration. Pp. 97-103. In: Lowe, A.T. and C.T. Smith (Comp) “Developing Systems for Integrating Bioenergy into Environmentally Sustainable Forestry” Proceedings of the IEA Bioenergy Task 18 Workshop and joint workshop with Task 25, 7-11 September 1998, Nokia, Finland. New Zealand Forest Research Institute, Forest Research Bulletin No. 211.

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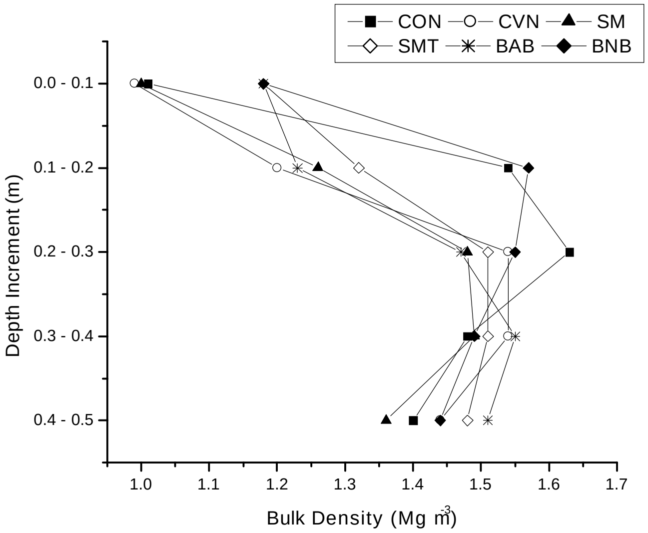
Figure 1. Bulk density for the mineral (A) and organic (B) sites (Sanchez et al. 2000).

A



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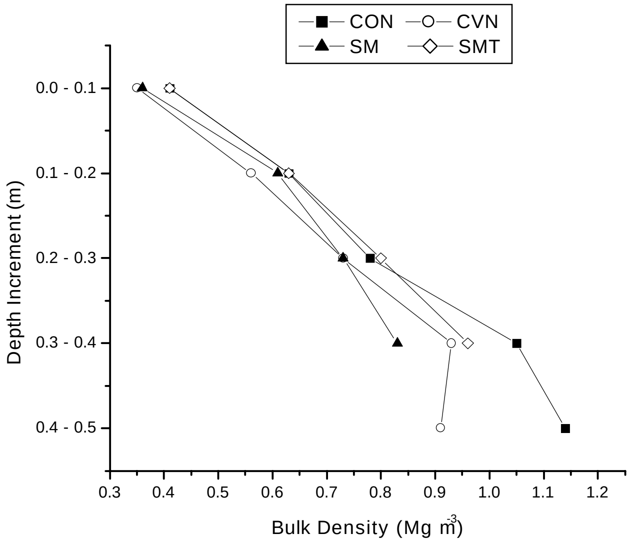


Figure 2. Mean cone index for the mineral (A) and organic (B) sites (Sanchez et al. 2000).

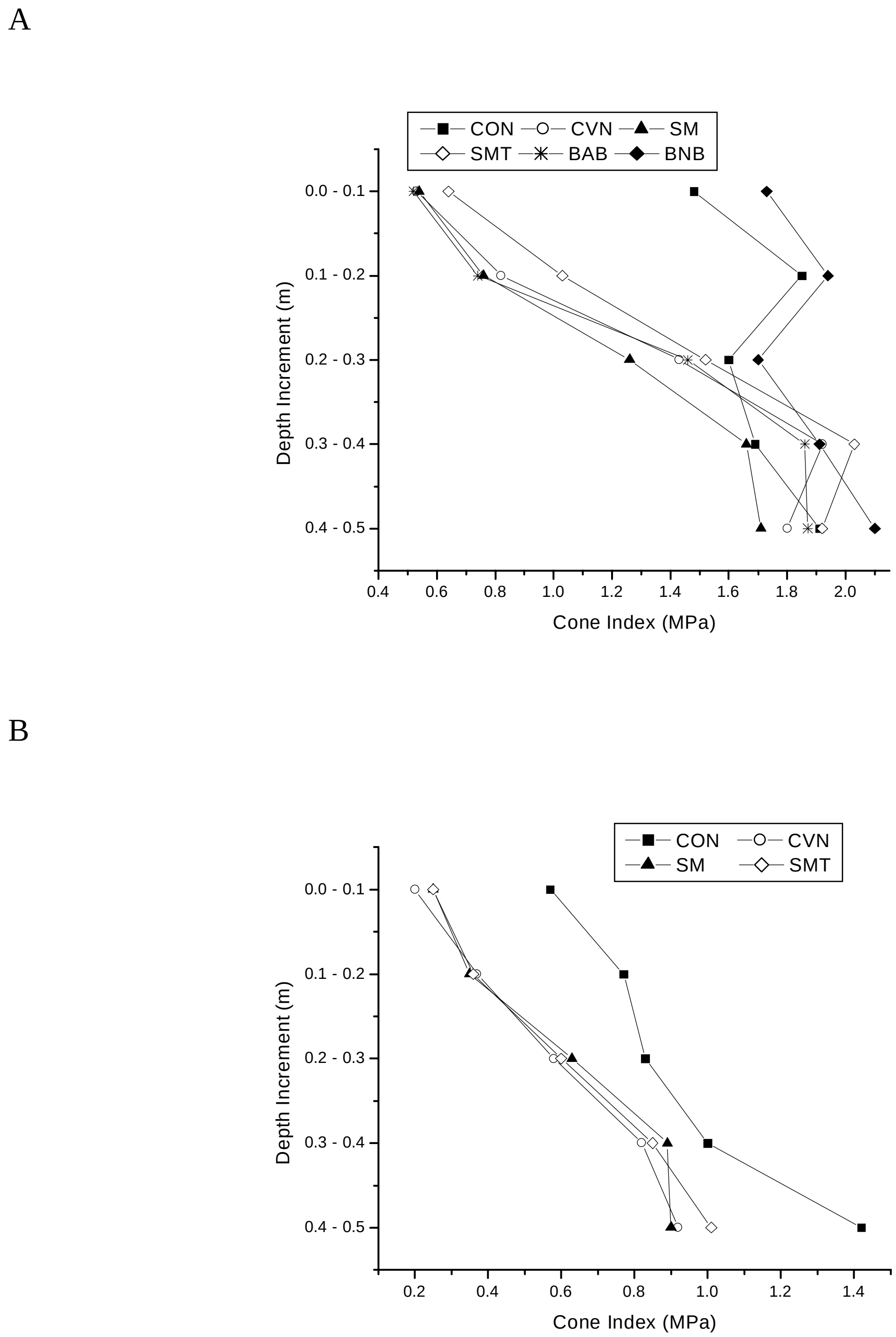
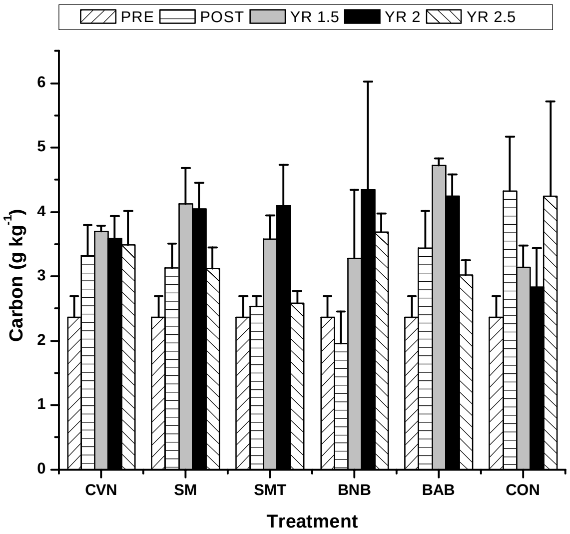


Figure 3. Soil carbon (A) and nitrogen (B) for the mineral site.

A



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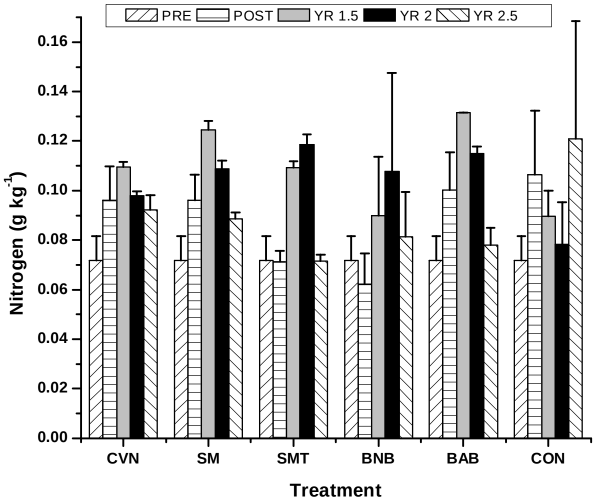
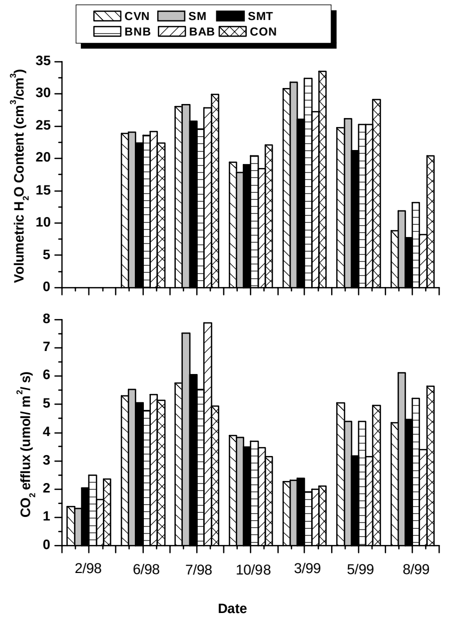


Figure 4. CO_2 efflux and volumetric water content measurements on the mineral (A) and organic (B) Site

A



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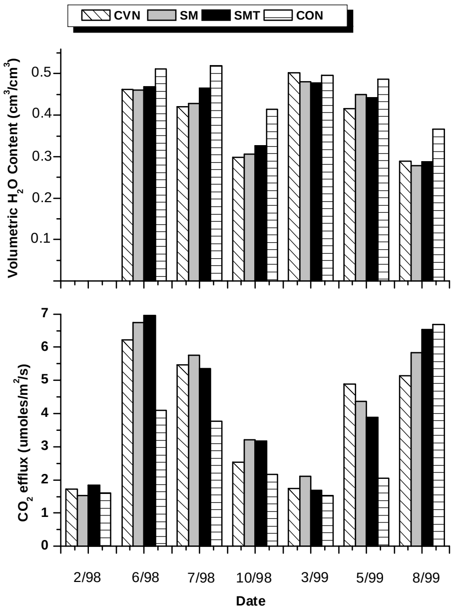
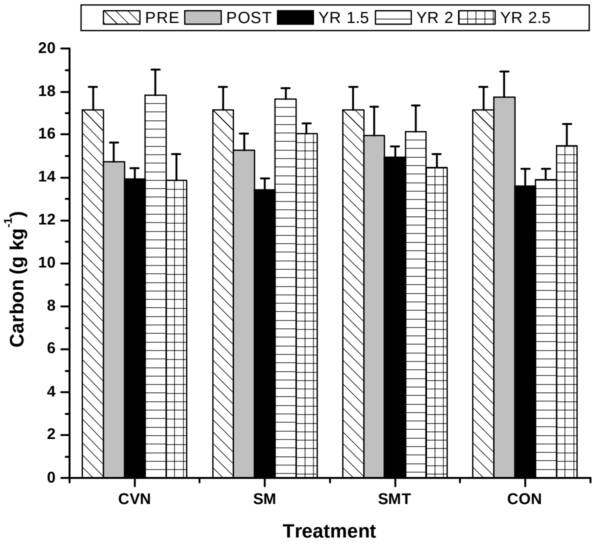


Figure 5. Soil carbon (A) and nitrogen (B) for the organic Site.

A



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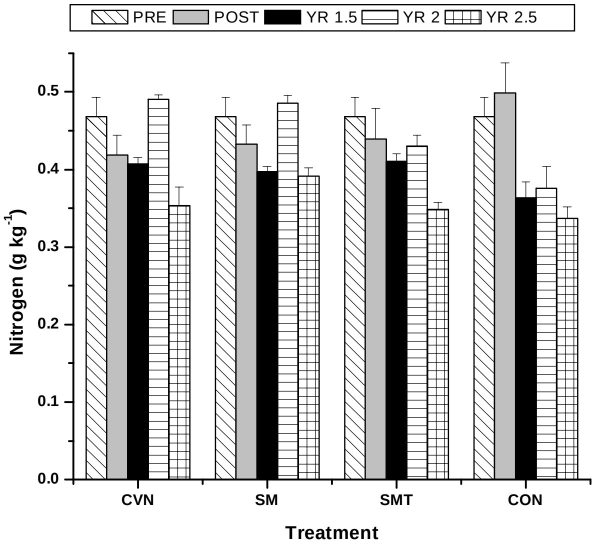

Figure 6. Tree height measurements for the mineral (A) and organic (B) site.