THE EFFECTS OF ROOT- PRUNING ON PRODUCTIVITY IN AN ALLEY CROPPING SYSTEM IN THE GEORGIA PIEDMONT, USA

by

JONATHAN J. REICHLEN

(Under the Direction of CARL F. JORDAN)

ABSTRACT

A non-irrigated alley cropping system, with Albizia julibrissin (mimosa) as the hedgerow tree species and Zea mays (field corn) as the alley crop, was studied during a two year period (2002-2003) to examine the effects of root interactions on productivity.

Three randomly placed treatments were established within 4 separate blocks to determine the effects of root interactions on crop and hedgerow productivity. In one block all biomass was retained from hedgerow prunings and crop residue on the soil surface within the alleys (biomass addition). Three blocks had hedgerow prunings and crop residues excluded for the purpose of accentuating the effects of root interactions (biomass exclusion). Treatments consisted of a root-prune and installation of a root barrier (barrier), a root-prune without a root barrier (trench), and a control with neither a root-prune nor a root barrier (control).

Maize biomass and height during 2002 was significantly greater for both the barrier and the trench treatment when compared to the control. There were no differences between treatments during 2003 for any of the biomass exclusion blocks, but the biomass addition block did have significantly greater height for both the barrier and the trench when compared to the control. Maize biomass and height were greater in 2003 than in 2002.

Total N concentrations in both maize plants and roots showed no difference between treatments for 2002 or 2003, but did show a significant difference between years, with 2002 being greater than 2003.

Total N concentration in soils showed no difference between treatments, blocks, or years.

Results of soil water content comparison between treatments showed no differences for either 2002 or 2003, but the biomass addition block had greater soil water content, for 8 of the 9 sampling dates, than any of the three biomass exclusion blocks during the experiment.

There were also no differences between treatments or blocks for mimosa pruning biomass production.

A five year drought in Georgia concluded at the end of 2020, and rainfall was above average during the growing season during 2003, therefore results from root-pruning between years is assumed to be an effect of soil water content availability and competition. Root-pruning appears to have a positive effect on productivity for non irrigated alley cropping systems in the Georgia Piedmont. Additionally, there is a positive effect on productivity with the retention of aboveground biomass within the alley cropping system. Further study would enhance the efficacy of results from this experiment for both drought years and average rainfall years.

INDEX WORDS: Alley cropping, Root-pruning, Albizia julibrissin, Zea mays, Productivity, Tree/crop competition

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B.S., VIRGINIA POLYTECHNIC AND STATE UNIVERSITY, 1997

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2004

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August 2004

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Introduction

For thousands of years agriculture has been a central component of land use. Early agriculture was based on a few simple objectives: to maintain fertility and food production (Titi 2003), but since the advent of soil tillage, the capacity of the land to sustain agricultural production has been deteriorating (Hillel 1991). The tripling of world population over the past fifty years has placed added pressures upon the planet and its ecosystems. Increases to population have historically been associated with accelerated and unmanaged land clearing and intensified use of existing lands (Francis and Youngberg 1990). Desertification, decreased yields, species extinctions, loss of genetic biodiversity, build up of pest and disease infestations, habitat destruction, water contamination, soil loss, and global warming are all problems that have been exacerbated by recent population increases and unsustainable agricultural practices.

Modern agricultural productivity has been, in large part, maintained through external inputs such as inorganic fertilizer, herbicides, and petroleum. Now evidence of environmental degradation and public health problems has helped to promote environmental regulations limiting amounts and use of certain external inputs within developed countries. Unfortunately, unregulated distribution and use of these external inputs in developing countries is now leading to severe environmental degradation and health problems (Bull 1982). Scientists, farmers, and concerned citizens have been questioning the ecological sustainability of high-input ecologically simplified production systems. The growing concern surrounding sustainability and agriculture has brought a portion of the scientific community to focus on ecosystem function and biodiversity to develop a system that is more environmentally friendly. The goal is to create a sustainable and environmentally sound food production.

Agriculture had historically been an integral component of humans' physical and biological surroundings. One system utilized by Native Americans consisted of agricultural plots that were tilled with hoes and planted with dibble-sticks. They planted various varieties of maize, beans, tobacco, and squash. Agricultural lands were planted with multiple crops in rotation as well as simultaneously. The benefit of multiple crops was to decrease impacts of insects as well as to use space more efficiently. A common practice to increase fertility was to bury fish innards and heads in close proximity to crops to enhance soil fertility. Maize was planted in the early season with borders of sunflowers to attract beneficial insects. As the maize began to mature beans were planted, which then used the maize stalks as a means of support. The beans would fix nitrogen and after harvesting would be incorporated into soil where it would help maintain soil fertility. As agricultural productivity began to decline, plots of land would be left to fallow over for a number of years and another plot of land would be used to increase fertility and repel pests. There were other methods adopted as well. Bear grease was used for its distinct odor that repulsed pests and also added nutrients to the soil (Lienhard 1975).

In contrast, modern agriculture has been a practice of ecological simplification and productivity maximization for the benefit of economic profitability. Commercial seed-bed preparation and mechanized planting have replaced the dibble stick; chemical herbicides, fungicides, and pesticides replaced natural controls on weeds, pathogens, and insects; and genetic manipulation replaced natural plant evolution and selection (Altieri 1999). This shift in agricultural management has created highly manipulated agricultural systems that require constant human intervention. Decomposition is even manipulated because plant biomass is harvested and soil fertility is maintained through applications of chemical fertilizers and not natural nutrient cycling (Ockerby et al 1999). A drastic loss of native plant varieties and biodiversity has now been linked to widespread adoption of genetically engineered, high yielding crops (Cleveland and Soleri 1989).

A new agricultural paradigm is needed. It is obvious that as the most influential organism on the Earth, it is the responsibility of humans to take precautions to evade irreconcilable degradation. Agricultural systems will need to integrate technological innovations, agricultural policy changes, and an understanding of the sustainability of resources, people and their environment.

Alternative Agriculture

Over the past 30 years there has been an emergence of alternative systems of management where natural ecosystems' structure, function, and biodiversity are viewed as models for establishing and sustaining agriculture. Central to all forms of agriculture is the issue of sustainability and productivity, but the definition of sustainability is completely dependent upon the stakeholders who are involved. In addition, the parameters used as measures of sustainability are completely dependent upon the opinion of the stakeholders. Productivity is equally as difficult to define because different professionals use different forms of valuation. Agronomists may use harvest material as a measure of productivity, economists may use net profit, and ecologists may use primary productivity. While defining sustainability and productivity within agricultural systems may be difficult, consensus may occur through indicators of non-sustainability, non-productivity, and/or environmental degradation (Kettler 1995) such as decreasing crop productivity, decreasing primary productivity, and environmental contamination.

Agroecology and agroforestry have emerged as ideas that go beyond the application of conventional practices to the development of systems with minimal dependence on chemicals and energy inputs. There is an emphasis on complexity within agricultural systems in which ecological interactions and synergisms between biological components provide the mechanism for the systems to maintain their own fertility, productivity and crop protection (Altieri and Rosset 1995). Both agroecology and agroforestry arose as alternative approaches developed to study and advance low input management systems for small scale farmers. They are based upon enhancing biological diversity and promoting internal regulation of functions through increased plant biodiversity and recycling of energy and nutrients (Altieri 1989; Gliessman 1990; Swift and Anderson 1993).

Biodiversity

Biodiversity refers to all species and plants, animals and micro-organisms existing and interacting within an ecosystem (Vandermeer and Perfecto 1995). Biodiversity has been used as an indicator of ecosystem sustainability and productivity. Conway (1997) states that as diversity within an agricultural system increases, productivity and sustainability tend to increase as well. Increases in biodiversity have been shown to enhance various ecological functions besides the production of food, fiber, fuel, and income. Biodiversity enhances nutrient cycling, regulation of microclimate and local hydrological processes, pest suppression and chemical filtration and detoxification (Altieri 1999). However, there has been growing debate over whether or not biodiversity is as important as functional group stability. While a system may have high biodiversity it does not mean that all functional groups are maintained and if certain functional groups are not present, a system can lose productivity and will not be sustainable. Advocates of biodiversity state that in order to maintain functional groups it is necessary to have higher diversity within those functional groups to avoid the breakdown of a functional group. Altieri (1994), states that increases in biological diversity provide greater stability for maintaining ecosystem functions.

Biodiversity has characteristically been separated into above-ground and below-ground systems without emphasizing that the two are interrelated and/or interlinked. This disconnect between above- and below-ground is a consequence of difficulty in examining and quantifying below-ground systems. Above-ground species identification of higher plants is more precise than identifying belowground species. One major hurdle for scientists at the moment is trying to identify belowground biodiversity. Wardle (2002) states that identifying macrofaunal groups is feasable, but for many groups of smaller soil organisms, quantifying species richness is extremely difficult. Klopatek (1992) states that it is probable that only about 1% of bacteria and 3% of nematodes species have been described. It is essential that research begin to fill the void in knowledge with respect to below-ground diversity and function in order to better understand agricultural systems.

Agroforestry

As an alternative form of agriculture, agroforestry mimics many of the ecosystem functions found in nature. Agroforestry is defined as an agricultural system where trees are grown together with annual crops and/or animals, resulting in enhanced complementary relations between components, and stimulating multiple use of the agroecosystem (Nair 1982). Agroforestry attempts to bridge the gap between unsustainable conventional agriculture and natural ecosystem function.

Agroforestry has been widely promoted over the past 20 years, but has its origins in other forms of non-traditional agriculture. These forms of agriculture evolved for different reasons. Some farmers protect and leave trees because of their sacred value while others leave them simply because they are too big, provide shade, or bear fruit (Iyamabo 1989). Foresters have recognized the usefulness of combining trees and food crops to enhance soil fertility, provide interim income, and utilization of soil, light, and other production factors in a more efficient way than is possible through sole cropping.

An important consideration for analysis of agroforestry systems is the fact that in a majority of cases, components of the system are ‘unequal,’ the trees being dominant and perennial and crops being annual. These interactions can be considered continuous as opposed to seasonal and are dependent on the system’s tree component (Roa et al 1998).

Alley Cropping

During the 1970’s alley cropping originated as a concept through work done at the International Institute of Tropical Agriculture (IITA) using leguminous tree/crop interactions as a way of increasing land use intensity while improving soil fertility (Kang et al. 1981).

Many alley cropping systems depend on the presence of N fixing trees and cover crops. In 1888, Beijeriinck identified the rhizobia bacteria as the catalyst for dinitrogen fixation in association with legumes (Havelka et al. 1982). This symbiotic relationship between rhizobium and legume makes it possible to sustain levels of productivity in agriculture, but does not occur without a cost. Legumes must provide an energy source to the bacteria in the form of fixed carbon from the initial infection of root hairs to nodule development. In return the rhizobium converts atmospheric dinitrogen gas into ammonia which is then taken up by the host plant or exuded into the surrounding rhizosphere. Under the appropriate conditions contributions of nitrogen from legumes can be substantial. However, situations like drought or degraded soils may increase competition between trees and crops and outweigh the contributions of nitrogen and organic matter from trees.

Alley cropping can provide windbreak protection and reduce soil erosion. Under the right conditions alley cropping has the potential to improve and maintain many components of the system. Increases have been observed in soil organic matter through additions of tree prunings, root turnover, and crop residues (Schroth and Zech 1995) and increased soil nitrogen through nitrogen fixation (Dommergues 1995) and deep root N capture (Hauser and Kang 1993). Alley cropping has increased transformations of inorganic unavailable forms of P into available forms (Hands et al. 1995). Additionally it has the potential to improve soil aggregation and porosity, reduce bulk density, cause hardpan breakup, increase microbial biomass, vascular arbuscular mycorrhizal, and rhizobia, and decrease insect pests, pathogens, and weed populations.

Alley cropping is by no means a system that has performed favorably in all cases and there are specific considerations when implementing this type of system. Three years after hedgerow establishment, Machado (1993) found that the hedgerows still did not provide sufficient biomass to maintain an alley cropping system in the Georgia Piedmont. Hedgerow trees can take up to 5 years to produce a sufficient amount of biomass for weed suppression or to maintain soil fertility. They can occupy upwards of 25% of the total land base that might have been used for crop production. What has emerged from research is that there are a number of factors such as lag time, rainfall, soil type, and species selection that affect the success of a particular system. In a comparison of short (< 3 years) and long term (> 4 years) yield success of

50 alley cropping research experiments, Young (1997) found that short term success was observed in approximately 40% of the cases and long term success in approximately 80% of the cases. This short term failure can have substantial influence on whether or not a farmer is going to adopt a particular practice and may also constitute a period of adjustment for which the farmer is not willing to wait. More research is needed with respect to long term experiments, but unfortunately this is a constraint of circumstance that is related to the lifespan of grant proposals and/or graduate research.

Roots

Root studies have shown that hedgerow trees' roots can extend laterally to 5 meters or more, completely crossing alley widths in some cases (Hauser 1993b). Hedgerow roots will therefore affect and be affected by inter-row crop roots within the alleys. The presence of perennial root systems within alleys can improve soil structure and create macro-pores which in turn increases water infiltration and reduces water runoff and soil erosion (Van Noordwijk 1991; Schroth and Zech 1995). Perennial hedgerow root systems can intercept and extract nutrients that would otherwise be leached through sole cropping (Seyfried and Rao 1991), but there is also evidence of negative effects of root interactions. Ssekabembe (1994) saw soil moisture reduced by 8% and 32% for crop-rows adjacent to hedgerows when compared to alleys where root barriers had been installed. As well, Korwar and Raddar (1994) found that root pruning to a depth of 30 cm increased soil moisture within the alleys. Through tillage, root trenching, or hedgerow pruning, root competition may be minimized during times of drought stress. Crop responses to reduced root competition through root pruning and/or root barriers have been observed in a number of cases (Singh et al 1989; Ong et al 1991; Roa et al 1991; Schroth et al; 1995; Hou et al 2003)

Other evidence points to a significant effect of above-ground pruning of hedgerows on crop performance either through additions of organic matter to the surface or through root turnover within the soil (Schroth and Lehmann 1995; Kadiata 1998; Peter and Lehmann 2000; Isaac et al 2003). Evidence shows that there is a substantial amount of natural root turnover with hedgerow trees and consequently a significant influence on soil structure, soil organic matter and nutrient status (Schroth and Zech 1995).

Objectives

The objective of this study was to examine the response of maize yield and total soil and plant N to three different tree/crop root interactions. In addition yields were examined for responses to pruning biomass addition or exclusion.

Hypotheses to be tested were:

1. The elimination of tree/crop root interaction would reduce competition and increase crop yields.
2. The elimination of tree/crop root interaction would increase total soil N.
3. The addition of pruning biomass within alleys would increase yield and total soil N compared to alleys where pruning biomass had been excluded

Methods and Materials

Site Description

The Alley cropping experiment was conducted at an experimental farm in Madison County, Georgia, located in the Southeastern United States (33° 57’ N lat. 83° 19’ W long.) within the Appalachian Piedmont. Average annual precipitation and temperature are 1200 mm and 18°C respectively.

The soil is an Ultisol of the Madison series (clayey, kaolinitic, thermic, typic, hapludults) (Soil Survey staff, 1992). Soil texture is sandy loam, with 77% sand, 15% silt, and 8% clay.

The site was originally farmed with cotton, during the early part of the 20th century, then with soybean until it was abandoned. The site is now vegetated with a number of weed species: Lespedeza striata (annual lespedeza), Rubus sp (blackberry), Allium vineale (wild onion), Ambrosia artemisifolia (ragweed), Erigeron canadensis (horseweed), and Heterotheca subaxillaris (camphorweed) (Leffler 1974). In January of 1990 the alley cropping experimental site was established using Albizia Julibrissin (mimosa) as a hedgerow species. The trees were planted 0.5 m apart within row and 4 m apart between rows.

Experimental Site Plan

The experimental design was a randomized complete block (Figure III.1). Beginning in September of 2001, three blocks were delineated for exclusion of mimosa prunings (MLE, URE, and MRE) and two blocks, which had previously been in fallow for 10 yr, were delineated for inclusion of mimosa prunings (UF and LF). Labels for each block represent location and biomass treatment. Block MLE is middle left exclusion, block URE is upper right exclusion, block MRE is middle right exclusion, block UF is upper fallow, and block LF is lower fallow. If a block label ends in an E then that block is a biomass exclusion block. If a block label ends in an F then that block was in fallow and is a biomass addition block. All five blocks had three treatments. The three treatments consisted of a root-prune and installation of a root barrier (barrier), a root-prune without a root barrier (trench), and a control without a root-prune or root barrier (control).

The three biomass exclusion blocks (MLE, URE, and MRE) were 20m x 12m. Each block consisted of three alleys, with an area for each treatment of approximately 12m x 6.3m. The biomass exclusion blocks had been previously managed during 2000 and 2001 with winter cover crops Trifolium incarnatum (crimson clover) and Triticale aestivum (winter wheat) and a summer crop of Sorghum bicolor (sorghum). The exclusion of biomass within these three blocks was done for the purpose of accentuating the effects of the treatments without the influence of above-ground organic matter. The exclusion also mimics many systems in the developing world where farmers utilize hedgerow prunings and alley biomass for fuelwood and/or fodder.

The two biomass inclusion blocks (UF and LF) were 30m x 12m. Both blocks consisted of three alleys, with an area for each treatment of approximately 10m x 12m. The addition of biomass within these two blocks was done to see if there were differences between excluding or adding pruning biomass and non-harvested crop material on crop yields and total N.

Biomass exclusion/addition

Biomass exclusion was used for two reasons: 1) Biomass exclusion mimics the practices of many farmers utilizing alley cropping in the developing world today. As well as harvesting crops, farmers utilize hedgerow trees and crop residues for fuelwood and fodder. 2) By excluding all above-ground biomass it was thought that treatment effects would be more evident.

Biomass addition was used because it follows recent trends with respect to sustainable agricultural, where crop residues are often left on the soil surface and conservation tillage practices are utilized.

Root pruning

Root pruning was done once for both trench and barrier treatments in March of 2002. A DitchWitch trenching machine created a trench approximately 15cm wide and .75 to 1m deep. Trenches were installed at .5m from the base of hedgerows for all 3 alleys within each treatment. Root barriers were 4mm thick plastic sheeting that was cut to fit and placed within the trenches and then backfilled with the previously excavated soil. The trenches in the trench treatments were backfilled with soil and did not have a root barrier installed.

Maize planting

Maize planting was done using a 2 row no-till planter. The planter consisted of a coulter blade followed by a 2 blade seed planter fed by a plastic hopper. The planting was done to a depth of approximately 10cm, with 75cm between rows and 15cm between plants. Estimating that 25% of landbase is occupied by hedgerows, the plant spacing equates to 66,700 plants/ha. Due to residue on the surface within the biomass addition blocks the planter was unable to penetrate to a sufficient depth within the soil and consequently seeds were then planted by hand.

Herbicide

Roundup herbicide was applied to alleys before the planting of sorghum in 2002 and before the planting of maize in both 2002 and 2003. The herbicide was applied at a rate of approximately 4.5L/ha using a backpack sprayer.

Timeline

2001

16 Dec.- Mimosa trees in the 2 biomass inclusion blocks were pruned to a height of 1m. Mimosa trees within these two blocks were 11 years old and had not been previously pruned. Because of their size the trees were cut to a height of 1m using a chainsaw and then chipped using a mechanical chipper. All chipped biomass was returned to the alleys within the blocks. The chipped biomass amounted to approximately 59,750 kg/ha for block UF and 129,275 kg/ha for block LF.

2002

16 Feb.- initial soil samples were taken.

22 March- root pruning was done using a Ditch-Witch mechanical trencher and root barriers were installed.

17 May- Roundup herbicide was applied to all alleys within the five blocks.

20 May- sorghum was planted within the alleys using a no till planter.

22 May- all above-ground plant biomass, within the alleys, was cut and removed from the three biomass exclusion blocks.

27 May- hedgerows in blocks MLE, URE, and MRE were pruned and removed.

18 June- applied Roundup herbicide to kill sorghum due to drought conditions.

19 June- planted maize within the alleys with a no-till planter.

3 July- hand planted maize in blocks UF and LF because no-till planter did not plant seeds at a sufficient depth for germination.

3 July- soil samples were taken.

16 July- pruned hedgerows in block LF and placed them within the alleys.

26 July- hedgerows in blocks MLE, URE, and MRE were pruned and removed.

28 Aug.- soil samples were taken

3 Sept.- soil samples were taken.

9 Sept.- soil samples were taken.

22 Sept.- harvested maize from blocks LF, MRE, URE, and MLE. Decided to eliminate block UF from the experiment due to extremely poor productivity for both the crops and hedgerows.

2003

23 April- applied Roundup herbicide to alleys of four remaining blocks.

24 April- hedgerows in block LF were pruned and placed within the alleys. Hedgerows in blocks MRE, URE, and MLE were pruned and removed.

5 May- all above-ground plant biomass, within the alleys, was cut and removed from the three biomass exclusion blocks.

9 May- planted maize within the alleys with a no-till planter.

12 May- soil samples were taken.

20 May- hand planted maize in block LF because no-till planter did not plant seeds at a sufficient depth for germination.

4 June- hedgerows in block LF were pruned and placed within the alleys.

4 June- hedgerows in block MRE were pruned and removed.

9 June- soil samples were taken.

29 June- soil samples were taken.

29 June- hedgerows in block URE were pruned and removed.

17 July- hedgerows in block MLE were pruned and removed.

18 July- soil samples were taken.

6 Aug.- harvested maize from block LF.

13 Aug.- harvested maize from blocks MRE, URE, and MLE.

Soil Sampling and Analysis

During the 2002-03 growing season, nine soil samples were taken from each treatment within each block to a depth of 10 cm. The soil sampler extracted a volume of approximately $30cm^3$ All samples were bulked by block, weighed, placed in an oven and dried at 105ºC for a minimum of 48 hours, and weighed again. The gravimetric soil moisture was calculated by the difference in weight before and after oven drying.

To obtain total soil N, dried soils were ground and passed through a 2-mm sieve, ball-milled to less than 250 um particle size, and weighed (25-30 mg, with ug digits significant) into 5 x 5 mm tin capsules. Total soil N was measured using Micro-Dumas combustion analysis.

Plant Sampling and Analysis

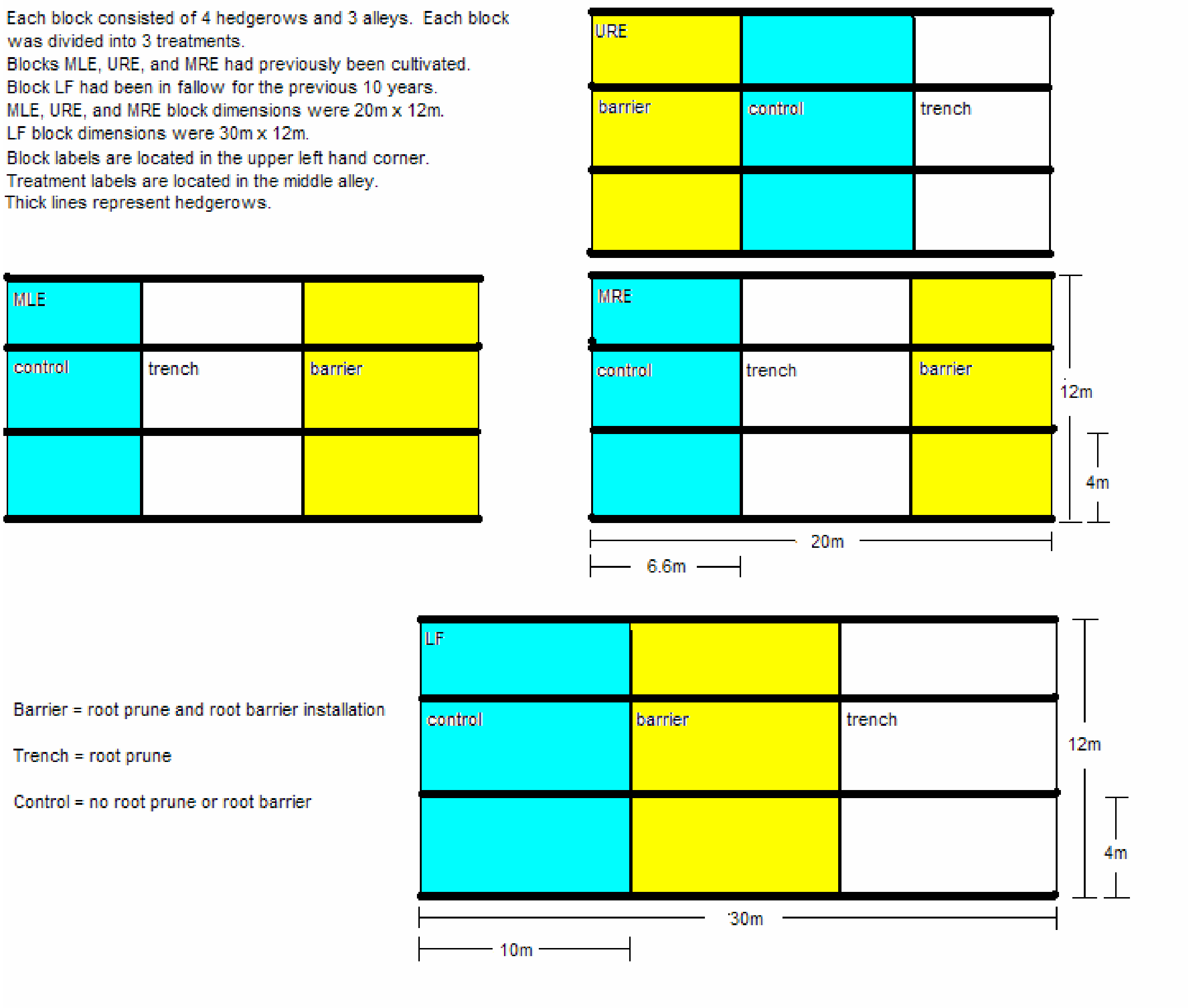
During the 2002 maize harvest, four randomly placed 1-m row length samples were taken for each treatment within each block. During the 2003 maize harvest, six randomly placed 1-m row length samples were taken for each treatment within each block. Number of plants per sample was recorded along with heights for each plant within the sample. Roots were excavated using a shovel and small hand held rake. Plants were harvested and separated as above-ground and below-ground biomass and were bulked (combined) for each sampling point.

Bulked above-ground samples were weighed, placed in an oven and dried at 50ºC for a minimum of 48 hours, and weighed again. Dry weight was used for biomass comparisons. Moisture content was calculated by the difference in weight before and after oven drying. Bulked below-ground sample were hand washed to remove soil and other non-living root matter, weighed, placed in an oven and dried at 105 degrees centigrade for a minimum of 48 hours, and weighed again. Dry weight was used for biomass comparisons. Moisture content was calculated by the difference in weight before and after oven drying.

To obtain total plant N, dried samples were processed as described for total N.

Statistical Analysis

Comparisons were made using student's t-test within the JMP version 4.0.4 (SAS Institute Inc.) statistical package. Significance was tested between treatments across blocks and between years for treatments. Due to logistical constraints associated with the size of block and treatment design, randomized replications for treatments could not be done within blocks. Therefore, statistical comparisons within individual blocks could not be done, but figures for individual blocks' treatment means have still been included.



Each block consisted of 4 hedgerows and 3 alleys. Each block was divided into 3 treatments.
Blocks MLE, URE, and MRE had previously been cultivated.
Block LF had been in fallow for the previous 10 years.
MLE, URE, and MRE block dimensions were 20m x 12m.
LF block dimensions were 30m x 12m.
Block labels are located in the upper left hand corner.
Treatment labels are located in the middle alley.
Thick lines represent hedgerows.

Barrier = root prune and root barrier installation

Trench = root prune

Control = no root prune or root barrier

Figure III.1

Results

Yield Data for 2002

There was no grain yield for any of the four blocks during 2002 and therefore there were no differences between treatments (Figure IV.1).

Maize above-ground biomass (Figure IV.2) was significantly greater ($P < .05$) in trench than control treatments and greater in barrier than control treatments when compared across blocks. Trench and barrier treatments were not significantly different. When Blocks were compared (Figure IV.3) LF had higher yields than any of the other three blocks.

Maize below-ground biomass (Figure IV.4) was significantly greater in trench than control treatments and greater in barrier than control treatments when compared across blocks. Trench and barrier treatments were not significantly different. When Blocks were compared (Figure IV.5) LF had higher yields than any of the other three blocks.

Maize total biomass (above- and below-ground) (Figure IV.6) was significantly greater in trench than control treatments and greater in barrier than control treatments when compared across blocks. Trench and barrier treatments were not significantly different. When Blocks were compared (Figure IV.7) LF had higher yields than the other three blocks.

Maize plant height (Figure IV.8) was significantly greater in trench than control treatments and greater in barrier than control treatments when compared across blocks. Trench and barrier treatments were not significantly different.

Yield Data for 2003

Maize grain weight (Figure IV.1) showed no significant differences between treatments when compared across blocks. When Blocks were compared (Figure IV.9) LF had higher yields than any of the other three blocks.

Maize above-ground biomass (Figure IV.2) showed no significant differences between treatments when compared across blocks. When Blocks were compared (Figure IV.10) LF had higher yields than any of the other three blocks.

Maize below-ground biomass (Figure IV.4) showed no significant differences between treatments when compared across blocks. When Blocks were compared (Figure IV.11) LF had higher yields than any of the other three blocks.

Maize total biomass (Figure IV.6) showed no significant differences between treatments when compared across blocks. When Blocks were compared (Figure IV.12) LF had higher yields than any of the other three blocks.

Maize plant height (Figure IV.8) showed no significant differences between treatments when compared across blocks.

Plant % N was analyzed for two (LF and MRE) of the four blocks (Figure IV.13). LF appeared to have greater plant %N for both 2002 and 2003. When comparing blocks between years, 2002 was greater than 2003.

Root %N was analyzed for two (LF and MRE) of the four blocks (Figure IV.14). In both 2002 and 2003 LF appeared to have greater %N than MRE.

Soil %N was analyzed for two (LF and MRE) of the four blocks. In both 2002 and 2003 there were no differences between treatments for either LF (Figures IV.15 and IV.16) or MRE (Figures IV.17 and IV.18). When comparing blocks between years there were no differences.

2002 mimosa pruning biomass (Figure IV.21) was 15,300 kg/ha for LF, 18,400 kg/ha for MRE, 7,100 kg/ha for URE, and 7,000 kg/ha for MLE. 2003 mimosa pruning biomass was 18,200 kg/ha for LF, 15,600 kg/ha for MRE, 5,000 kg/ha for URE, and 5,100 kg/ha for MLE.

Soil moisture showed no differences between treatments for either 2002 (Figure IV.19) or 2003 (Figure IV.20), but LF had consistently higher % moisture for 8 of the 9 sampling dates.

Note

Significant differences at a 0.05 probability level are indicated by different letters (above columns) between treatments and different cases between years. Bars within columns represent std. error.

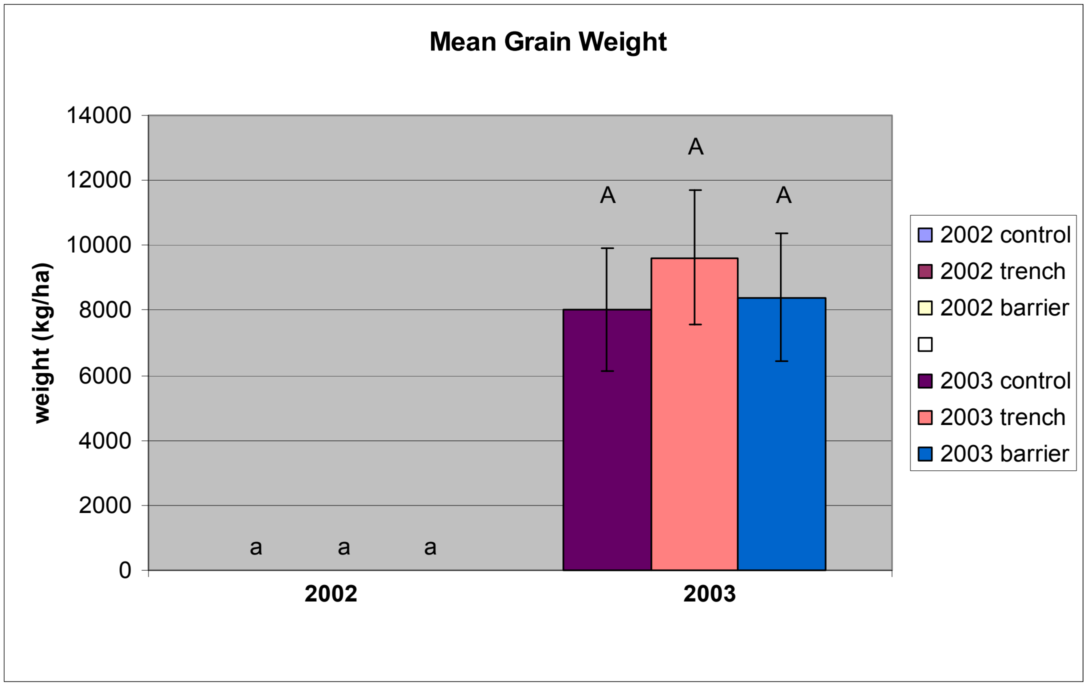


Figure IV.1

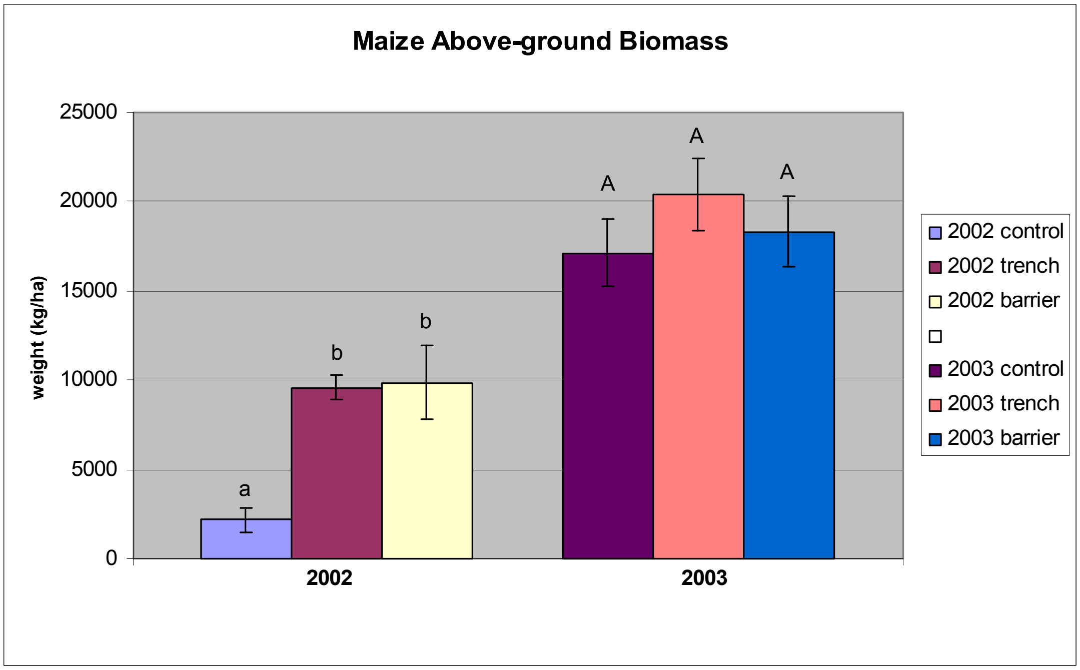


Figure IV.2

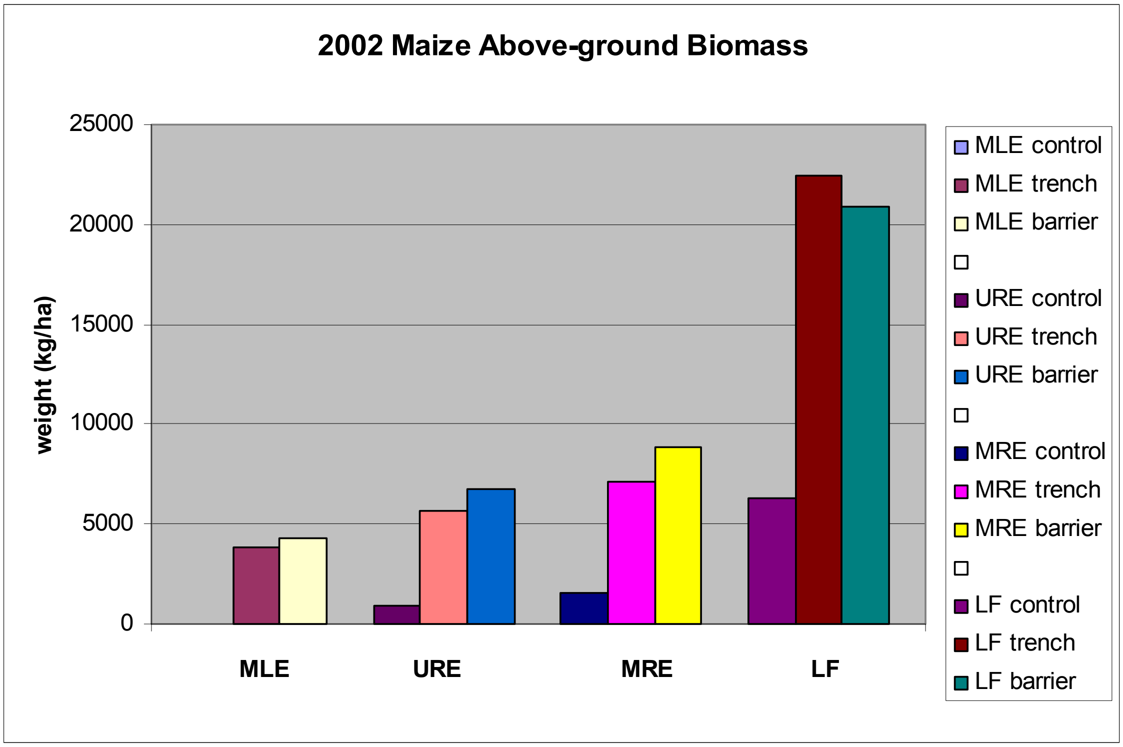


Figure IV.3

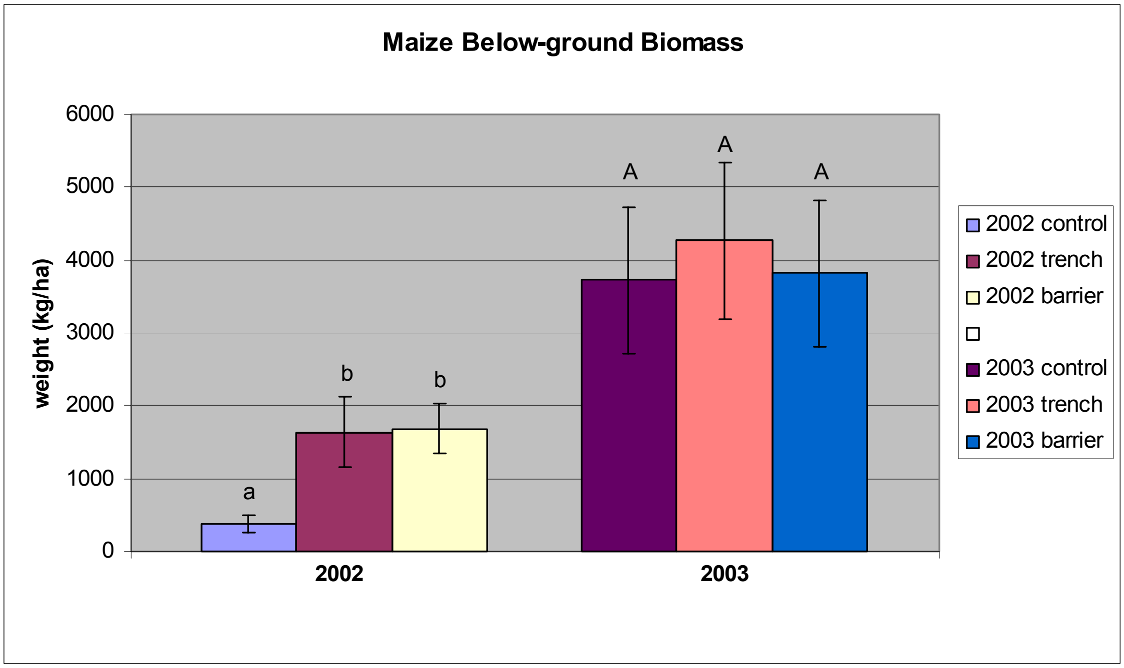


Figure IV.4

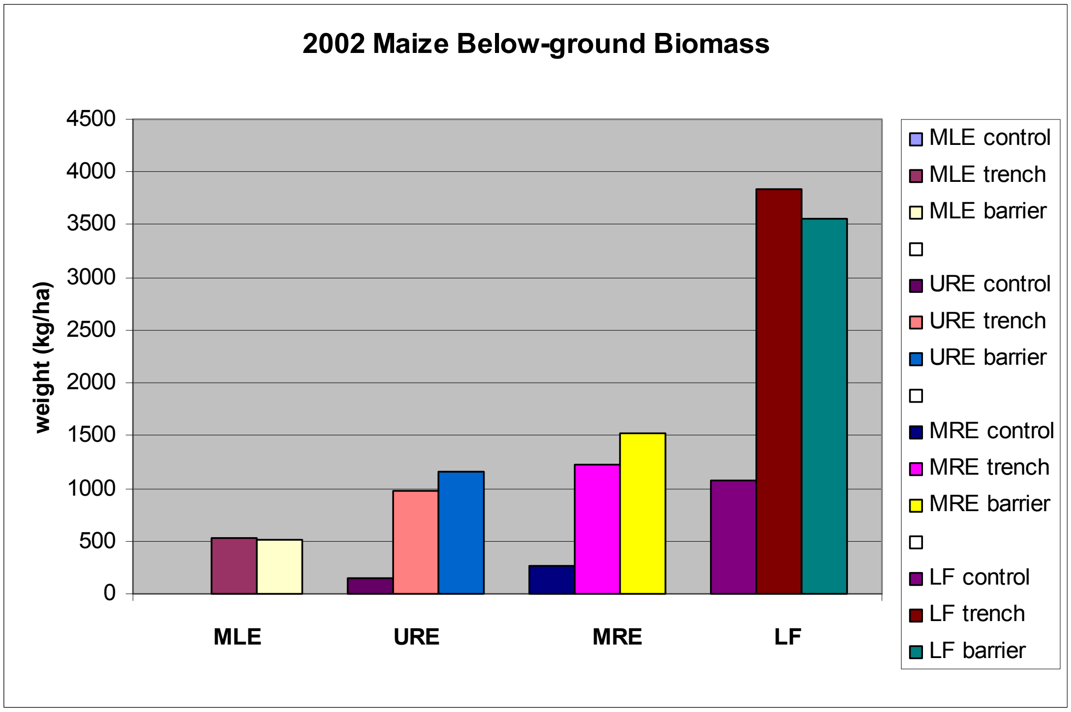
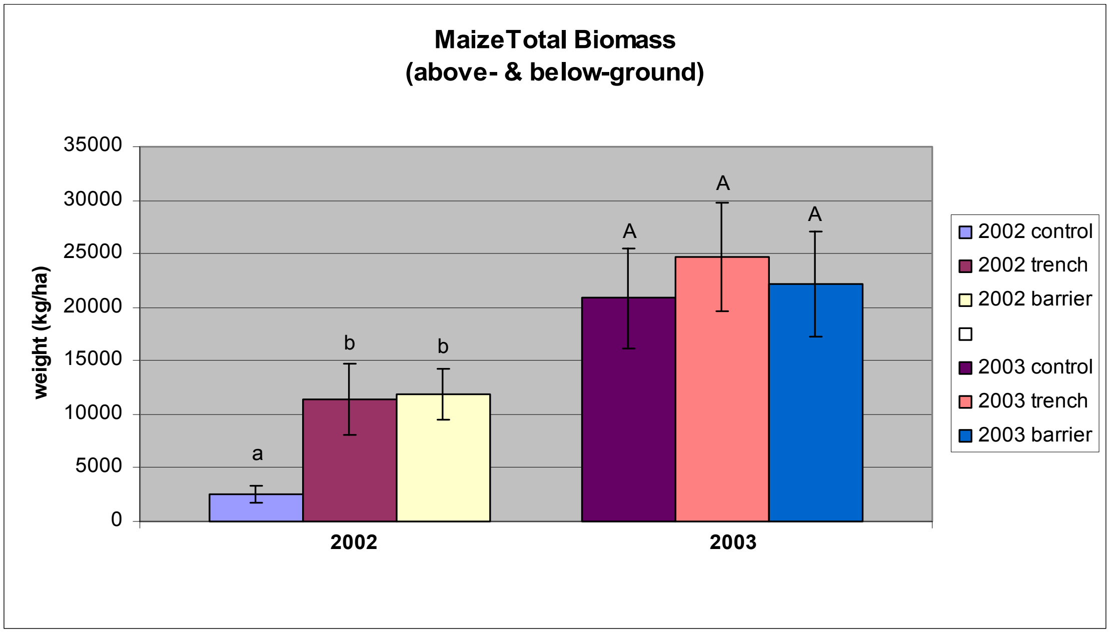


Figure IV.5



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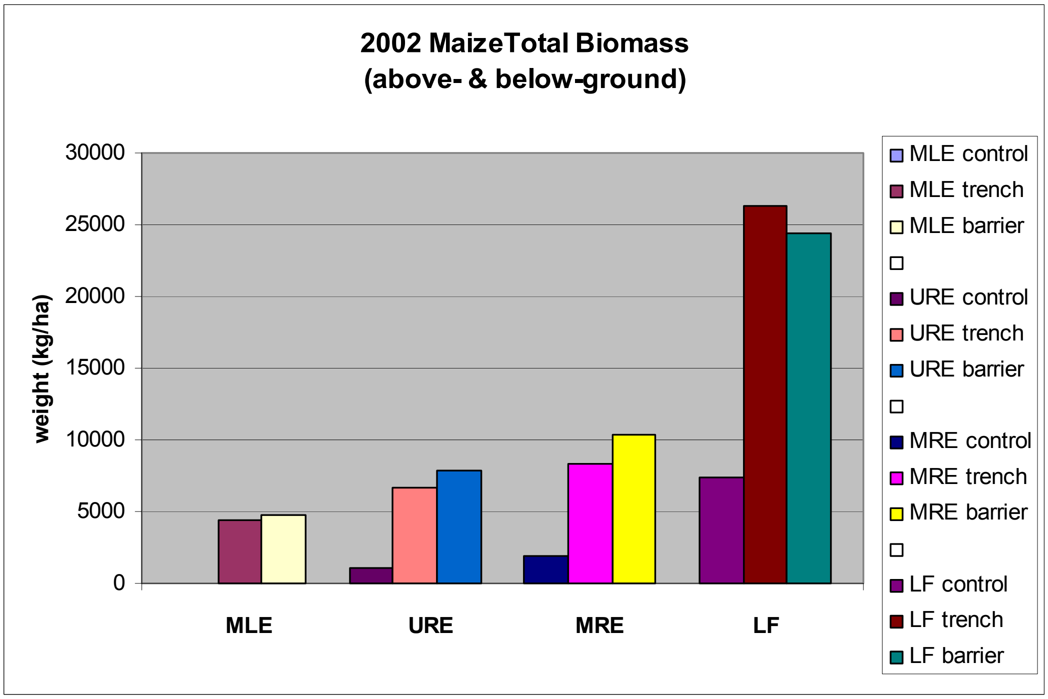

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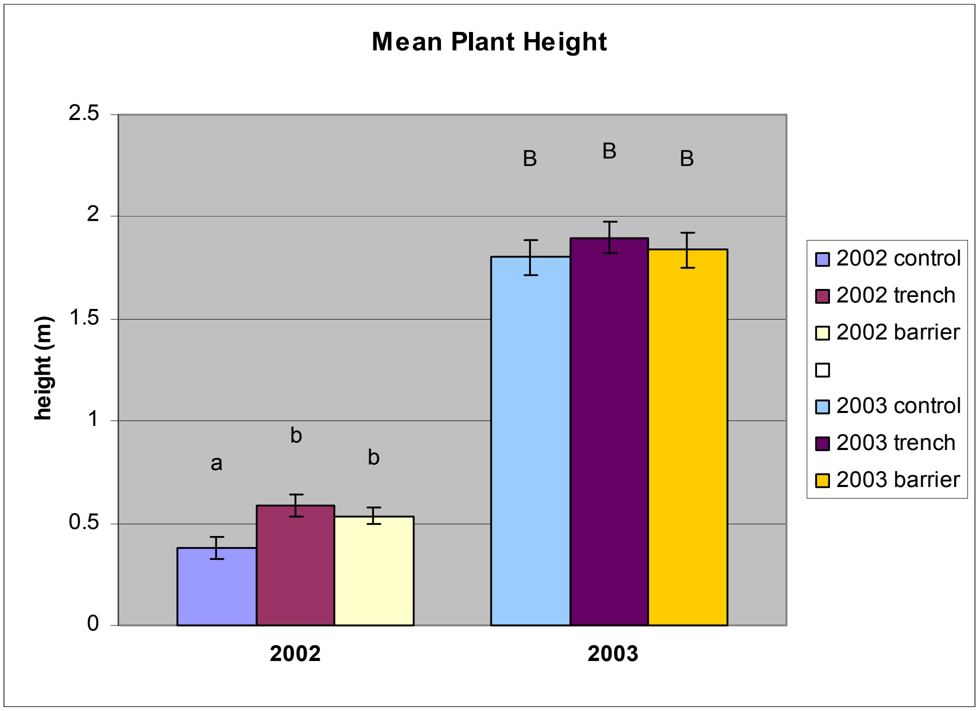

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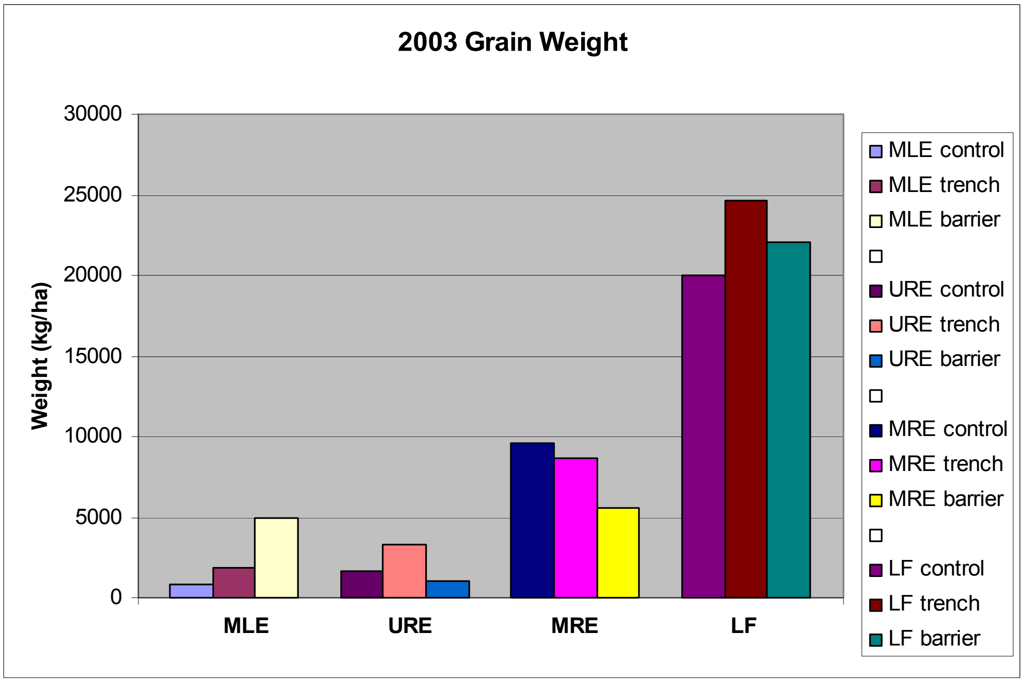

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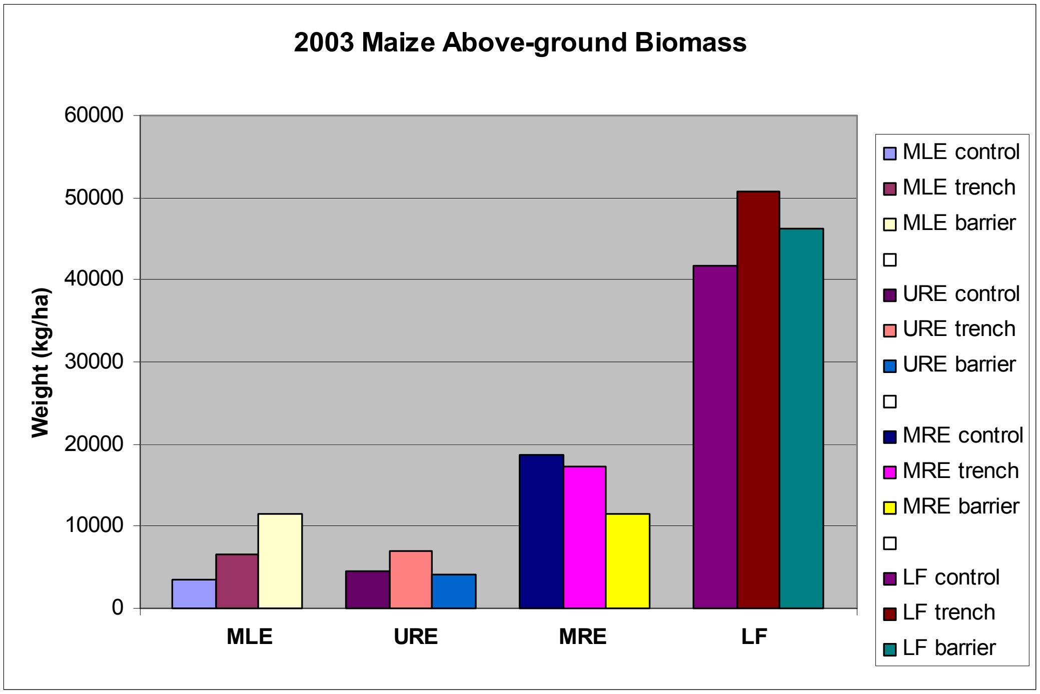

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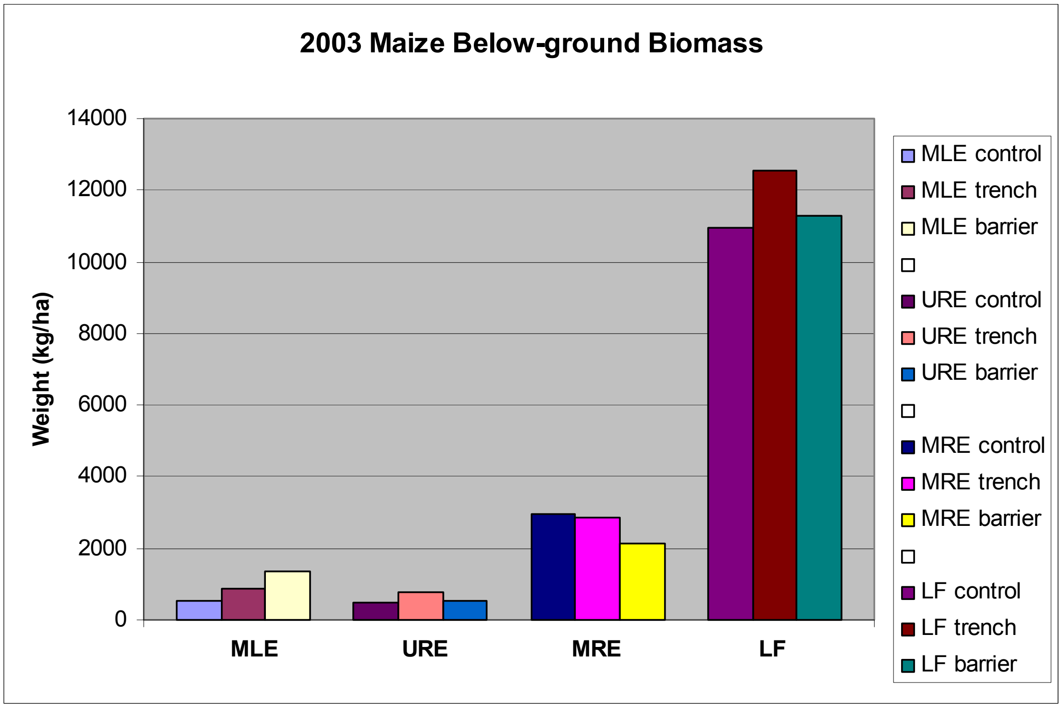

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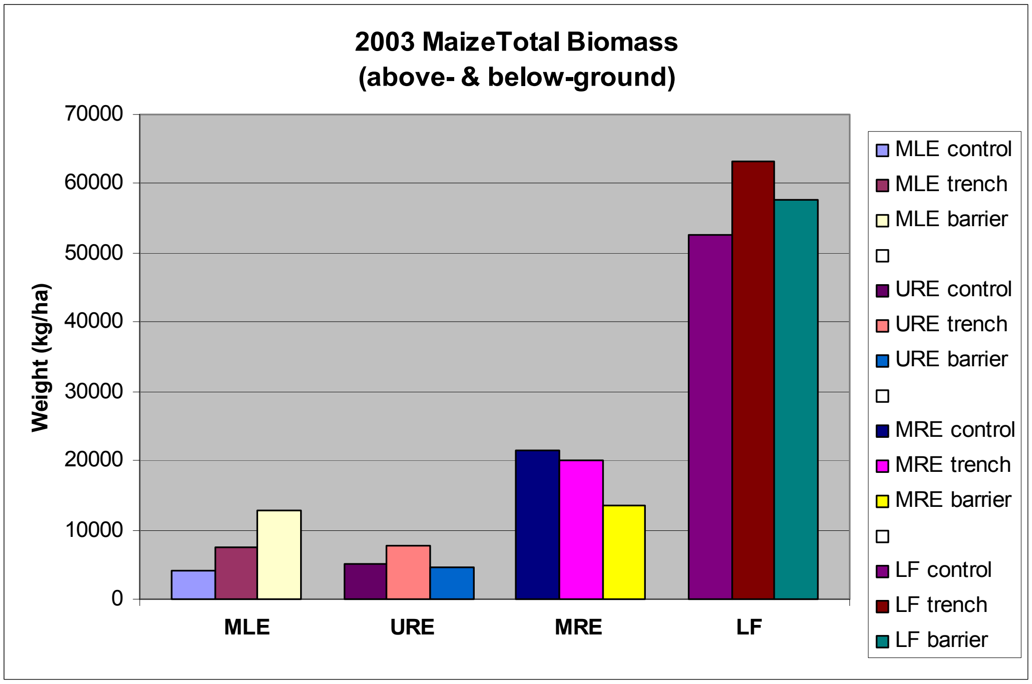

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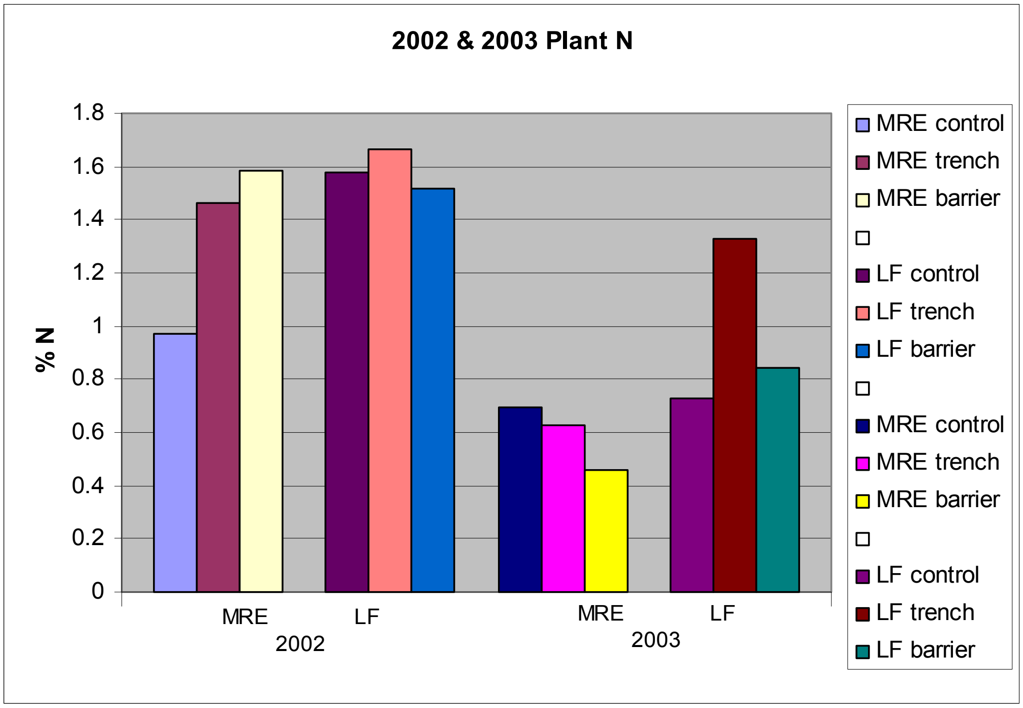

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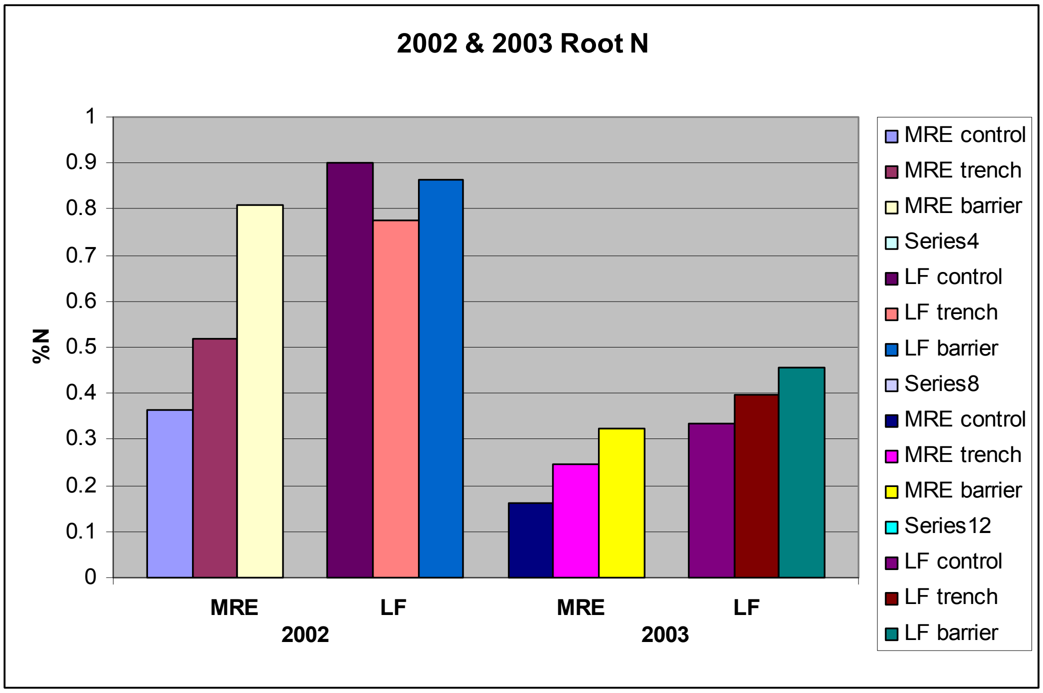

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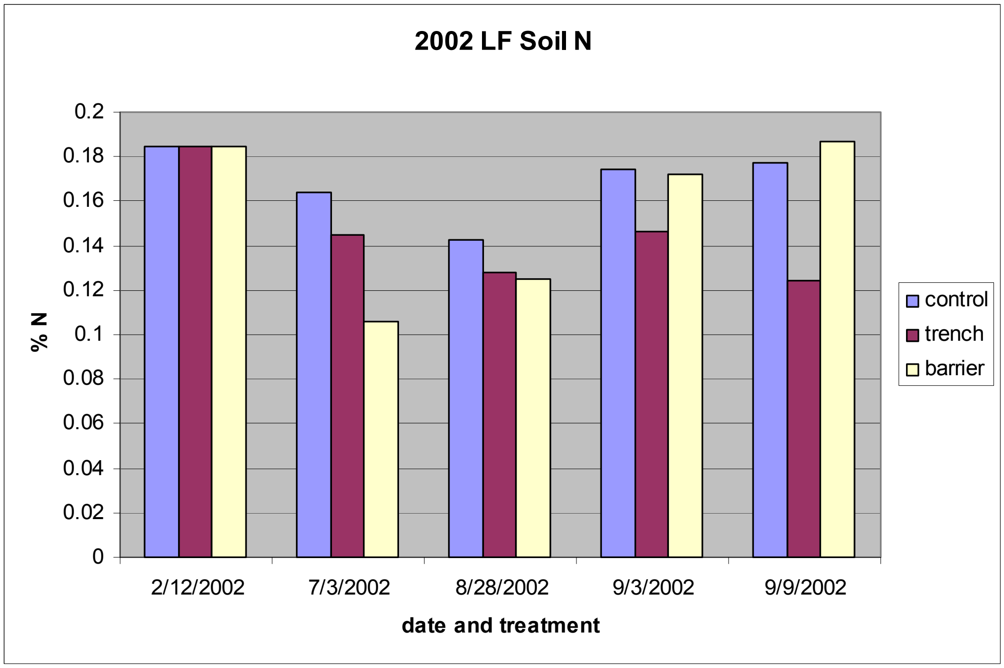

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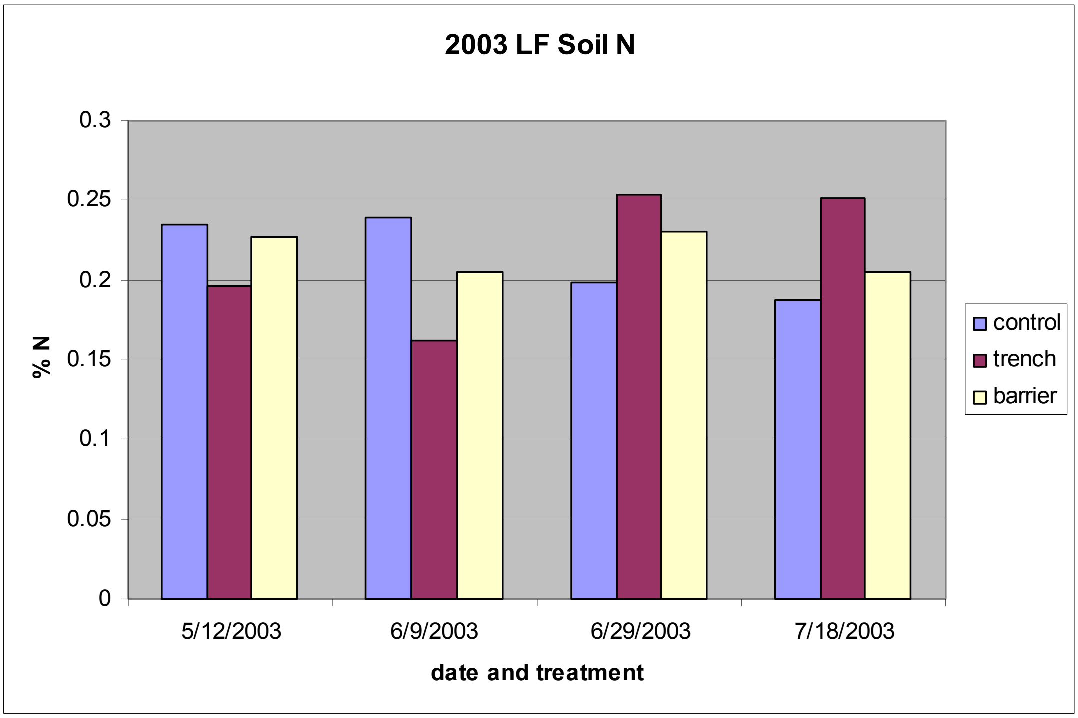

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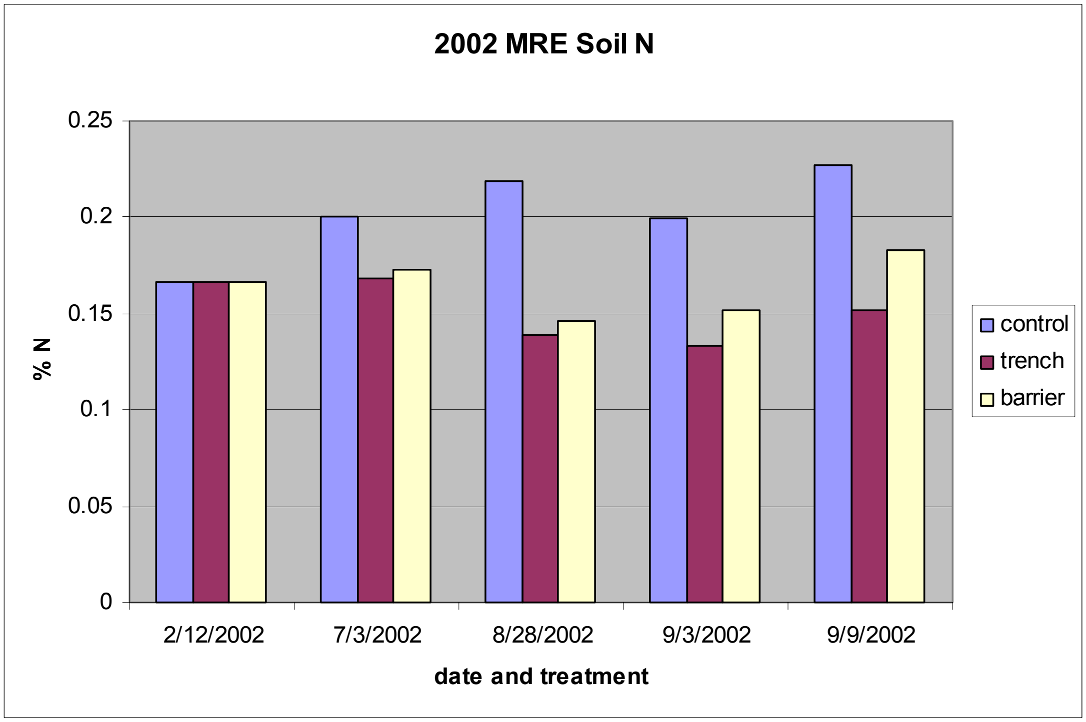

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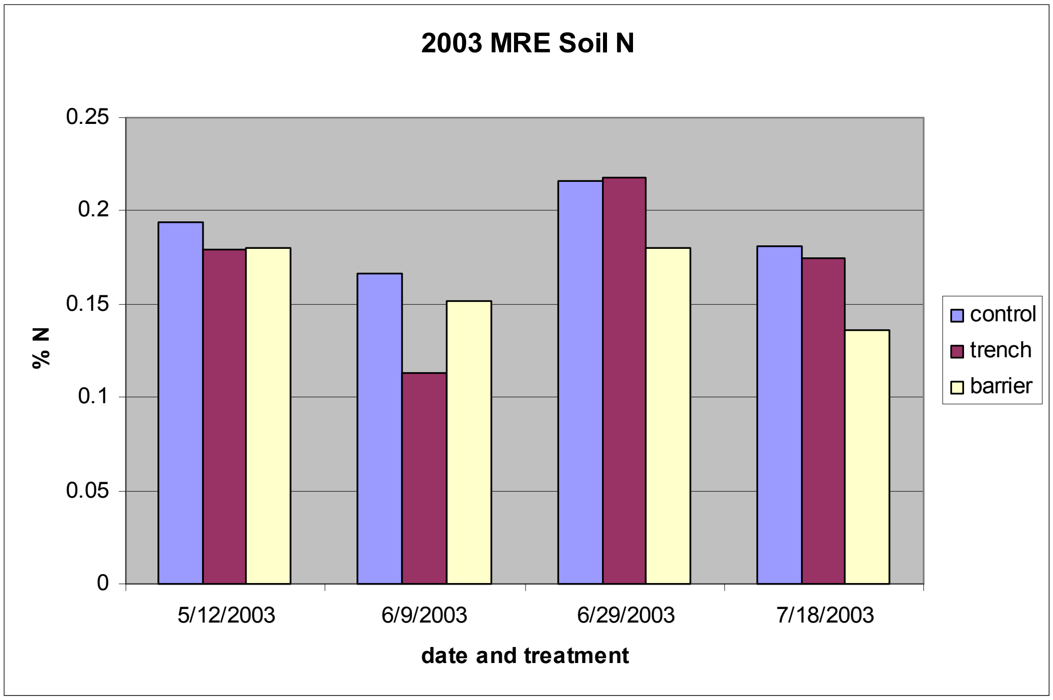

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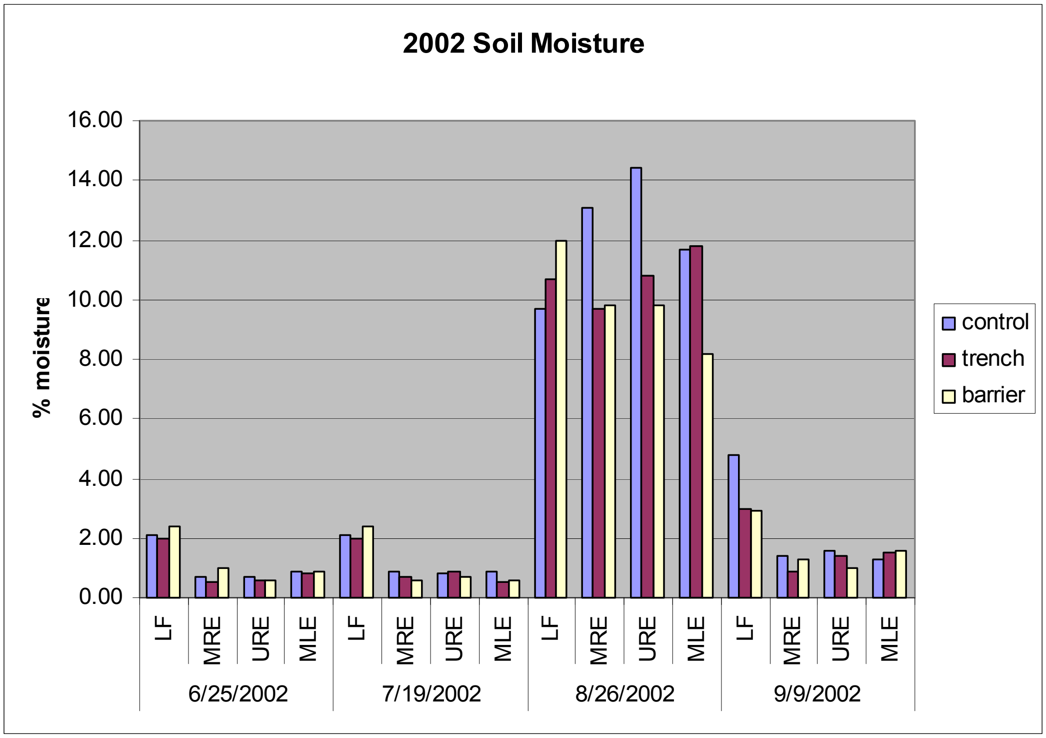

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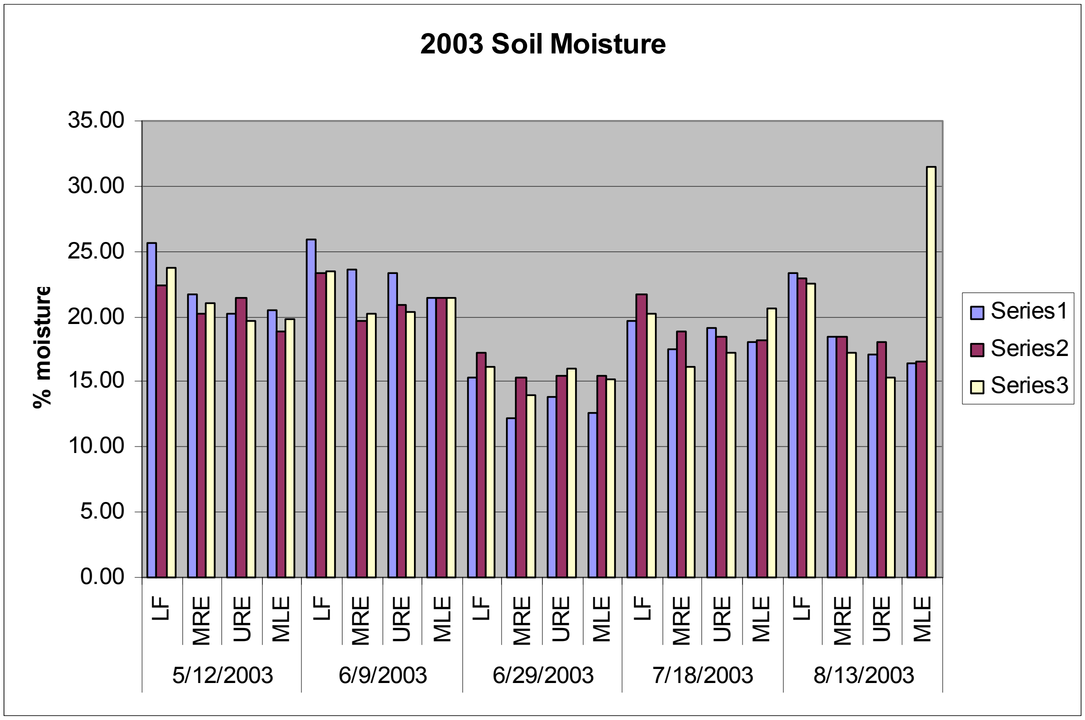

Figure IV.20

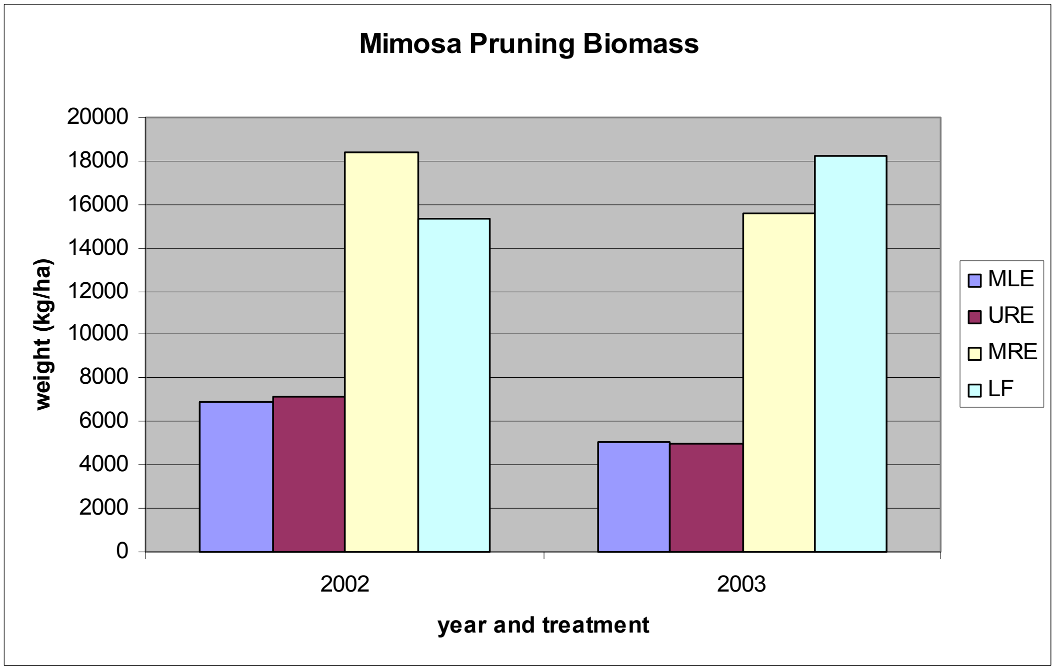

Figure IV.21

General Results and Discussion

Without eliminating the tree crop interface, alley cropping has been proven to be ineffective at sustaining crop production in areas of low rainfall (Kang 1993; Ong 1994). Root trenching and root barriers have proven to be effective tools for separating crop and hedgerow root systems and reducing competition for soil moisture in both the tropics (Singh et al. 1989) and temperate zone (Jose et al. 2000; Miller and Pallardy 2001). In addition to reducing root competition, soil moisture and crop yield were greater for alley cropping systems using root barriers.

Our experiment did not have any significant differences in soil moisture, but we conclude that there were differences in availability of soil moisture for maize as a result of higher yields within root pruned treatments. When moisture is limited there is a maximum root density that can be attained for this system. If hedgerow roots are left intact within the same soil that crops grow, crops yields will be negatively affected. By eliminating roots from the hedgerows within the alleys, crop roots are allowed to grow and utilize soil space that had previously been occupied. This accounts for differences in root biomass between the root pruned treatments and control treatments. Plant biomass and plant height were also significantly higher for the root pruned treatments, but only during 2002. As a result of the pre-existence of mimosa roots within the alleys, maize productivity suffered when water became a limiting factor.

2002 had significant differences in height between root pruned and non root pruned treatments and 2003 showed similar trends, although not significantly different. Differences in height are usually associated with competition for light, but may also point to competition for moisture, even when there is sufficient rainfall. Differences may also be a result of nutrient competition. There was greater plant and root % N in both root pruned treatments compared to control treatments. Large decomposing roots still present within the soil from the previous year's root pruning could have been supplying nutrients.

An alternative option to root pruning that may have some benefit for reducing root competition is pruning hedgerows above-ground just prior to planting. Shoot pruning or defoliation can contribute to significant root dieback or sloughing and has been observed in a number of experiments (Peter and Lehmann 2000; Hartley and Amos 1999; Chesney and Nygren 2002). Schroth (1999) states that factors such as shoot pruning can have positive effects on alleviating root competition in agroforestry systems. Another important component of root and shoot pruning is the release of carbon and nitrogen within the soil which may then be utilized by crops. While information concerning below-ground nutrient contributions is limited there is evidence that suggests that it may be just as important as contributions from surface applied prunings (Jose et al. 2000; Kadiata et al. 1998; Nygren and Ramirez 1995).

During 2002, Georgia experienced a significant deficit of rainfall (Figure V.1), which had been ongoing for the previous 4 years. The culmination of this drought event accentuated quite clearly the effects of root competition for water at the tree-crop root interface. Both root pruning (trench treatment) and root pruning with a root barrier (barrier treatment) proved to be important in eliminating root competition and increasing crop yields during the drought.

Experiments have shown effects of root competition through decreased crop production in rows adjacent to trees as apposed to rows that were located within the center of alleys (Haggar and Beer 1993; Singh et al. 1989). Our experiment showed no trends with respect to stronger competition for crop rows, associated with plant height, adjacent to hedgerows.

During 2003 there was above average rainfall (Figure V.2) during the growing season and there were no statistical differences between treatments when compared across blocks. There was still an observed difference between both trench and barrier treatments and control treatments in 2002. The differences seen between years points to a constraint with alley cropping: if there is insufficient water to satisfy the alley crops and the hedgerow trees then the hedgerow trees will compete with the alley crops and consequently diminish crop yields. If a farmer utilizes irrigation or is located in an area without drought problems then competition may not be a factor.

Georgia Piedmont soils are highly weathered Ultisols with low organic matter and nutrient reserves. Erosion and physical and chemical degradation have been have been ongoing over the past 150 years as a result of conventional agricultural practices. Conventional agriculture has been shown to reduce soil carbon from 1.33% in forests to .92% after only three years of conventional cultivation (Giddens 1957). It is now nearly impossible to cultivate without adding large quantities of external supplements.

Hedgerows have the potential to supply organic matter to improve physical, chemical and biological characteristics of soils. Higher microbial biomass was found in alley cropping systems than when compared to conventionally tilled soils and was attributed to large amounts of pruning biomass from hedgerows and its slow rate of decomposition (Yamoah et al. 1986). Greater abundance of earthworm casts within alley cropping were also associated with higher quantities of hedgerow prunings and increased soil moisture compared to non-alley cropping systems (Kang et al. 1989). Hedgerows can also provide a vital barrier for reducing soil erosion. By reducing rates of erosion hedgerows can help maintain soil fertility, improve water holding capacity, increase water infiltration, and improve soil structure. It is important to note that since a large portion of soil fertility is located in the topsoil it is especially sensitive to even small rates of erosion (Young 1997). Even though there were no significant differences in soil moisture between blocks, LF had higher % soil moisture for 8 of the 9 sampling dates.

The hedgerow species used in this experiment was mimosa, Fabaceae Albizia julibrissin. Mimosa has evenly bipinnate deciduous leaves (Radford et al. 1968). Mimosa is a N fixing legume native to China , Nepal, and Japan found mainly in tropical and subtropical areas up to 1600m in elevation (Zhou and Han 1984; Athar and Mahmood 1985; Shakya 1988). Brought to the United States for cultivation around 1745 it is currently found from Virginia to Louisiana along roadsides and in old fields (Rogers and Rogers 1991). Mimosa has been known for its sprouting vigor and difficulty in eradication, which is why it has good potential as an alley cropping hedgerow species in the Southeast.

Application of mimosa wood mulch and hedgerow prunings proved to be a superior method for crop production within our alley cropping system. Block LF outperformed the other three blocks on crop production for both years of the experiment (Figures IV.7 & IV.12). During 2003, mean biomass within block LF (Figure IV.12) showed that the root-pruned treatments did have higher mean weights for above- and below-ground biomass. The implication may be that there is some form of competition that is decreasing yields where hedgerow roots have not been pruned. Competition may be for moisture or nutrients within the surface layers, which throughout the growing season could lead to decreased yields. If hedgerow roots are established within alleys there will be competition of some form or another.

The amount of pruning biomass produced and applied in block LF amounted to 15,324 kg/ha in 2002 and 18,212 kg/ha in 2003 (Figure IV.21). Results from laboratory analysis showed that our mimosa leaves contained 3.65% N and stems contained 1.22% N. Through field measurements it was determined that approximately 66% of pruning biomass was stem and 44% was leaf. Using this data we concluded that 311.3 kg/ha and 370.1 kg/ha of N was applied within the alleys through pruning biomass.

Agricultural systems are traditionally measured by their productivity, so if a farmer were to consider using this type of cropping system then there would have to be comparable yields. Using yield data from the Georgia Agricultural Statistic Service, we compared average yields for non-irrigated maize grown in Georgia with yields we obtained in our experiment. Average yields for silage and forage were 17 tons per acre for both 2002 and 2003. Silage and forage are weighed as dry above-ground biomass. Above-ground biomass yields during 2002 and 2003 for block LF were 7.4 and 20.7 tons per acre. This data shows that during years of drought alley cropping will not support yields seen in conventional agriculture even with aide of root pruning, but when there is sufficient rain it does very well. It should be noted that if all of the above ground biomass were to be removed for harvest that this system would not be sustainable. Additional pruning biomass and or fertilizer would need to be added to supplement harvested biomass.

Further investigation into the effects of tillage on reducing root competition within alley cropping needs to be addressed. Root pruning may be a cost prohibitive practice by itself, especially when combined with certain conservation-tillage practices. If a farmer utilizes conventional tillage practices, then he/she may be averting root competition without even knowing it. Additionally, tillage can have the benefit of training hedgerow roots to grow to deeper portions of the soil. As roots infiltrate zones below alley crop roots, they can then act as filters for capturing and recycling nutrients that leach through the upper portions of the soil.

Deep tap roots also have the potential to mine untapped nutrients from lower depths within the soil profile.

Conventional tillage practices tend to benefit early crop growth by incorporating organic residues into the soil. The organic matter is then broken down and nutrients then become available for plant uptake. No-tillage practices tend to provide a slow, but steady amount of organic nutrients that continually become incorporated within the soil. This may be more sustainable in the long run, but issues of sustainability inevitably are also linked to production. If a farmer does not have sufficient economic return from agricultural practices then it will not be adopted.

Total N may not have been a very useful indicator of soil N availability considering that only small portions of this can be mineralized. Total N can give an indicator of whether or not the system is maintaining sufficient quantities of N to potentially sustain crop production (Tate 1995). Using the same alley cropping system that was sued for this experiment, Haberman (1995) found that contributions of N from decomposing hedgerow prunings was sufficient to maintain crop productivity.

Plant and root N concentrations were significantly greater in 2002 than 2003 even though biomass was significantly less. To explain this difference, Nilsen and Muller (1981) associated higher concentrations of ammonium and nitrate within roots and plants during drought periods with a decrease in transport and reduced nitrate reductase activity.

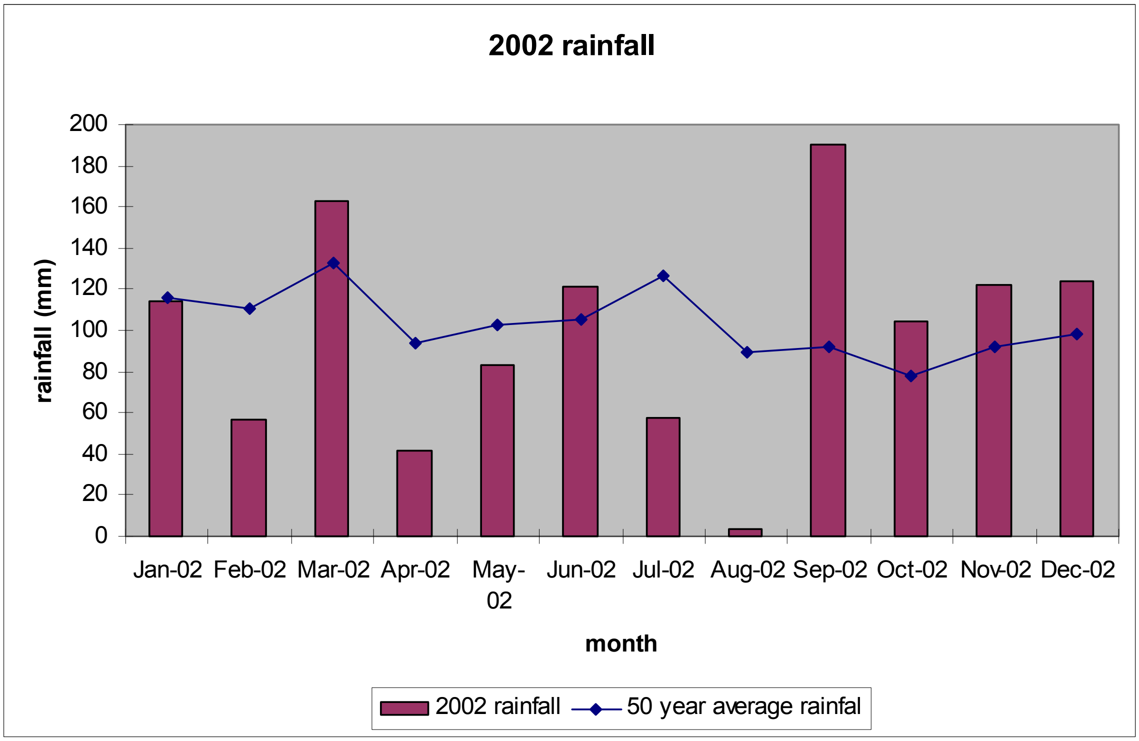

Figure V.1

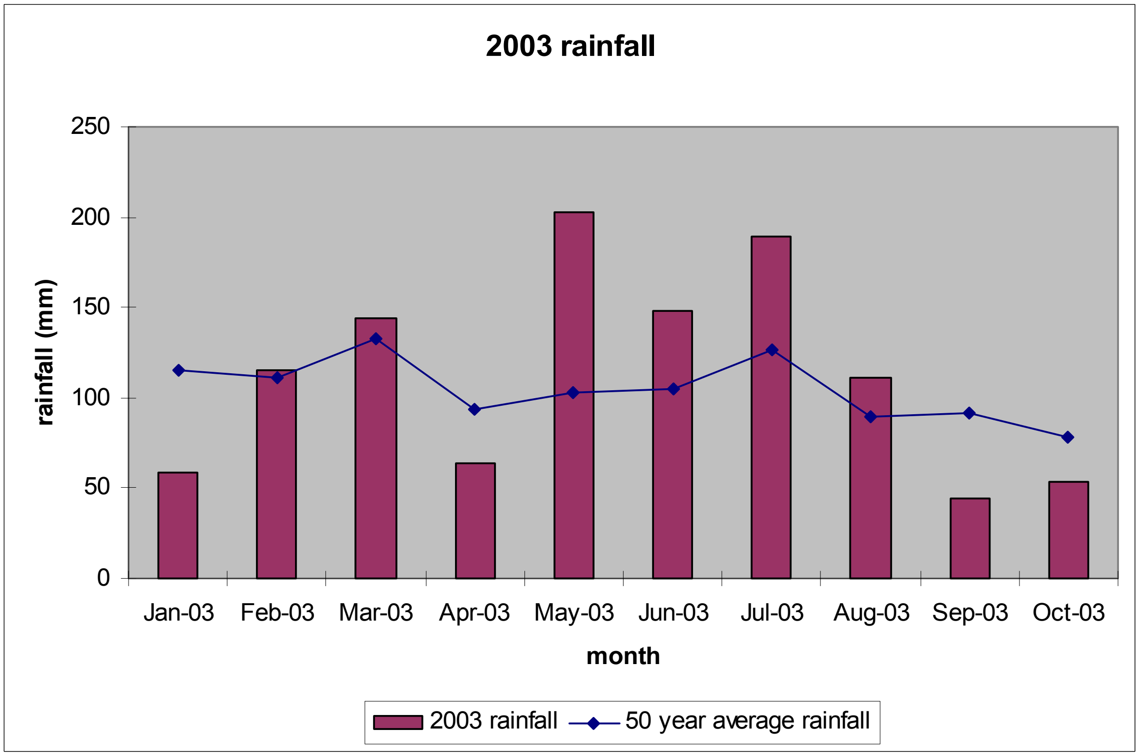

Figure V.2

Conclusions

1. When soil moisture is limiting, root pruning is an effective management practice for enhancing agricultural productivity within alley cropping systems in the Southeastern United States.
2. When soil moisture does not appear to be limiting, root pruning may still be beneficial in reducing competition for soil water and/or available nutrients near the soil surface and enhance agricultural productivity.
3. Mimosa hedgerows can produce sufficient pruning biomass to supply adequate quantities of N to sustain low-input alley cropping system growing maize.
4. Root pruning does not appear to affect total N for either soil or plant, but through the application of pruning biomass within the alleys it may.

References

Altieri, M.A. 1989. Agroecology: A New Research and Development Paridigm for World Agriculture. Agriculture, Ecosystems and the Environment. 27:37-46

Altieri, M.A. and P.M. Rosset 1995. Agroecology and the conversion of large-scale conventional systems to sustainable management. International Journal of Environmental Studies 50: 165-185.

Athar, M. and A. Mahmood 1985. Qualitative study of the nodulating ability of legumes of Pakistan. Tropical Agriculture 62: 49-51

Bull, R. 1982. A Growing Problem: Pesticides and the Third World. Oxfam. Oxford, England

Chesney, P. and P. Nygren 2002. Fine root and nodule dynamics of Erythrina poeppigiana in an alley cropping system in Costa Rica. Agroforestry Systems 56: 259-269

Cleveland, D.A. and D. Soleri. 1989. Diversity and the New Green Revolution. Diversity. 2/3:24-25

Dommergues, Y.R. 1995. Nitrogen fixation by trees in relation to soil nitrogen economy. Fertilizer Research 42: 215-230

Francis, C.A. and G. Youngberg. 1990. Sustainable agriculture- an overview. p.1-23. In C.A. Francis, C.B. Flora, and L.D. King (ed.) Sustainable agriculture in temperate zones. John Wiley & Sons, Inc. New York, NY.

Giddens, J. 1957. Rate of loss of carbon of Georgia soils. Soil Science Society of America Proc. 21: 513-515

Gliessman, S.R. 1990. Agroecology: Researching the Ecological Basis for Sustainable Agriculture. Springer Verlag. New York, NY.

Haberman, R.B. 1995. Nutrient cycling and availability in a multiple species alley-cropping system on the Georgia Piedmont. Ph. D. Dissertation. University of Georgia. Athens, GA.

Haggar, J.P. and J.W. Beer 1993. Effect on maize growth of the interaction between increased nitrogen availability and competition with trees in alley cropping. Agroforestry Systems 21: 239-249

Hartley, S.E. and L. Amos 1999. Competitive interactions between Nardus stricta L. and Calluna Vulgaris (L.) Hull: the effect of fertilizer and defoliation on above- and below-ground performance. Journal of Ecology 87: 330-340

Hauser, S. and B.T. Kang 1993. Nutrient dynamics, maize yield and soil organic matter dynamics in alley cropping with **Leucaena leucocephala**. In: Mulongoy K. and R. Merckx (eds) Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture. pp 215-222. John Wiley & Sons and Sayce Publishing, Chichester, UK.

Hauser, S. 1993b. Root distribution of Dactyladenia (Acioa) barteri and Senna (Cassia) siamea in alley cropping on ultisol. I. Implication for field experimentation. Agroforestry Systems 24: 111-121.

Havelka, V.D., M.G. Boyle, and R.W.F. Hardy 1982. Biological nitrogen fixation. In Nitrogen in Agricultural Soils. Agron 22: 365-422. Am. Soc. Agron. Madison, WI.

Hillel, D.J. 1991. Out of the earth: Civilization and the life of the soil. Free Press, New York, NY.

Hou, Q., J. Brandle, K. Hubbard, M. Schoeneberger, C. Nieto and C. Francic 2003. Alteration of soil water contentconsequent to root-pruning at a windbreak/crop interface in Nebraska, USA. Agroforestry Systems 57: 137-147

Isaac, L., C.W. Wood and D.A. Shannon 2003. Pruning management effects on soil carbon and nitrogen in contour hedgerow cropping with Leucaena leucocephala (Lam.) De Wit on sloping land in Haiti. Nutrient Cycling in Agroecosystems 65: 253-263

Jose, S., A.R. Gillespie, J.R. Seifert, and D.J. Biehle 2000. Defining competition vectors in a temperate alley cropping system in the Midwestern USA 2. Competition for water. Agroforestry Systems. 48: 41-59

Kadiata, B.D., K. Mulongoy, and B. Mambani 1998. Pruning effect on nitrogen nutrient release in the root zone of Albizia lebbeck and Leucaena leucocephala. Biol Fertil Soils 26:187-193

Kadiata, B.D., K. Mulongoy and N.O. Isirimah 1998. Effect of tree pruning and pruning application to trees on nitrogen fixation by Leucaena and Gliricidia. Agroforestry Systems 39: 117-128

Kang, B.T., G.F. Wilson, L. Sipkens 1981. Alley cropping maize (Zea mays L.) and Leucaena (Leaucaena leucocephala Lam.) in southern Nigeria. Plant and soil. 63: 165-179.

Kang, B.T. 1993. Alley cropping: past achievement and future directions. Agroforestry Systems 23: 141-155

Kang, B.T., A.C.B.M. van der Kruijs, and D.C. Couper 1989. Alley cropping for food crop production in the humid and subhumid tropics. In: Alley farming in the humid and subhumid tropics. Proceedings of an internation workshop held in Ibadan, Nigeria, 10-14 March 1986. (Eds.) B.T. Kang, L Renolds. 16-26. I.D.R.C., Ottawa, Canada.

Kettler, J.S. 1995. A Sustainable Strategy for Fragile Lands: Fallow Enrichment of a Traditional Slash-Mulch System in Coto Brus, Costa Rica. Ph. D. Dissertation. University of Georgia. Athens, GA.

Korwar, G.R. and G.D. Radder 1994. Influence of root prunning and cutting interval of leucaena hedgerows on performance of alley cropped rabi srghum. Agroforestry Systems 25: 95-109

Leinhard, B.D. 1975. Origins of American agriculture. John Wiley & Sons. New York, New York.

Leffler, L. 1974. Chemical composition of old field vegetation: a search for accumulator species. M. Sci. Thesis. University of Georgia. Athens, Georgia.

Machado, R. 1993. A comparison of productivity and nutrient dynamics between an alley-cropping system and an annual legume-based cropping system in the Piedmont region of Georgia, USA. Ph. D. Dissertation. University of Georgia. Athens, GA.

Miller, A.W. and S.G. Pallardy 2001. Resource competition across the crop-tree interface in a maize-silver maple temperate alley cropping stand in Missouri. Agroforestry Systems. 53: 247-259

Nilsen, E.T. and W.H. Muller 1981. The influence of low plant water potential on the growth and nitrogen metabolism of the native california shrub Lotus scoparious (Nutt. In T & G) ottley. American Journal of Botany 68: 402-407

Nygren, P. and C. Ramirez 1995. Production and turnover of N2 fixing nodules in relation to foliage development in periodically pruned Erythrina poeppigiana (Leguminosae) trees. Forest Ecology and Management 73: 59-73

Ockerby. S.E., A. L. Garside, S. W. Adkins, P. D. Holden 1999. Prior crop and residue incorporation time affect the response of paddy rice to fertiliser nitrogen. Australian Journal of Agricultural Research. Volume 50. Number 6

Ong, C.K., J.E. Corlett, R.P. Singh and C.R. Black 1991. Above and below ground interactions in agroforestry systems. Forest Ecology and Management 45: 45-57

Ong, C.K. 1994. Alley cropping – ecological pie in the sky. Agroforestry Today 6(3): 8-10

Peter, I. And J. Lehmann 2000. Pruning effects on root distribution and nutrient dynamics in an acicia hedgerow planting in northern Kenya. Agroforestry Systems 50: 59-75

Radford, A.E., H.E. Ahles, and C.R. Bell 1968. Manual of vascular flora of the Carolinas. The University of North Carolina Press. Chapel Hill.

Rao, M.R., C.K. Ong, P. Pathak and M.M. Sharma 1991. Productivity of annual cropping and agroforestry systems on a shallow Alfisol in semi-arid India. Agroforestry Systems 15: 51-63

Rogers, D.J. and C.R. Rogers 1991. Woody ornamentals for deep south gardens. University of West Florida Press. Pensicola

Schroth, G., N. Poidy, T. Morshauser and W.Zech 1995. Effects of different methods of soil tillage and biomass application on crop yields and soil properties in agroforestry with high tree competition. Agriculture, Ecosystems, and Environment 52: 129-140

Schroth, G. and W. Zech 1995. Above- and below-ground biomss dynamics in a sole cropping and an alley cropping system with Gliricidia sepium in the semi-decidious rainforest zone of West Africa. Agroforestry Systems 31: 181-198

Schroth, G. and J. Lehmann 1995. Contrasting effects of roots and mulch from three agroforestry tree species on yields of alley cropped maize. Agriculture, Ecosystems, and Environment 54: 89-101

Schroth, G. 1999. A review of belowground interactions in agroforestry, focussing on mechnisms and management options. Agroforestry Sytems 43: 5-34

Seyfried, M.S. and P.S.C. Rao 1991. Nutrient leaching loss from two contrasting cropping systems in the humid tropics. Tropical Agriculture 68: 9-18

Shakya, R. 1988. Indigenous nitrogen-fixing trees in the farmlands of Nepal. In: Multipurpose tree species for small farm use. Proceedings of an international workshop held November 2-5, 1987 in Pattaya, Thailand (Eds.) Withington, D., K.G. Macdicken, C.B. Sastry, and N.R. Adams. 125-130. I.D.R.C., Canada; W.I.I.A.D., Arlington, VI.

Sigh, R.P., C.K. Ong, and N. Saharan 1989. Above and below ground interactions in alley cropping in semiarid India. Agroforestry Systems. 9: 259-274

Soil Survey Staff. 1992. Keys to soil taxonomy, 5th edition. SMSS Technical Monograph No. 19. Pocahontas Press, Inc., Blacksburg, VA.

Ssekabembe, C.K., P.R. Henderlong and M. Larson 1994. Soil moisture relations at the tree/crop interface in black locust alleys. Agroforestry Systems. 25: 135-140

Tate, R.L. 1995. Soil microbiology. John Wiley & Sons, Inc. New York, New York

Yamoah, C.F., A.A. Agboola, G.F. Wilson, and K. Mulongoy 1986. Soil properties as affected by the use of leguminous shrubs for alley cropping with maize. Agriculture, Ecosystems, and Enviroment 18: 167-177

Young, A. 1997. Agroforestry for soil management. CAB International. New York, New York

Zou, X. and S. Han 1984. Studies on symbiotic system of nudule bacteria and tree legumes. I. Nodulation, isolation and reciprocal cross inoculation. J. Nanjing Inst. For. 2. 32-42