ABSTRACT

BROWN, ADAM CHRISTOPHER. Effects of Tree Competition by *Pinus taeda* on *Glycine max* in an Alley Cropping Agroforestry System in Eastern North Carolina. (Under the direction of Dr. Daniel Robison.)

Agroforestry is becoming increasingly attractive to small and medium size farmers in the United States looking to diversify their incomes. An experiment involving the intercropping of pine trees and soybeans in North Carolina was established in 2007 near Goldsboro, NC at the Center for Environmental Farming Systems (CEFS). The objective of the current study was to investigate tree competitive effects on soybean growth and development in the 2011 growing season by considering below ground and above ground interactions caused by shade and roots. Soybeans (*Glycine max*) were intercropped with loblolly pines (*Pinus taeda*) at a within-row tree spacing of 1.5 m by 2 m, and crop alley widths of 24 m. In each of four blocks, the sixteen rows of soybeans proximal to the strips of pines and environmental conditions near them were examined. In each block, there were areas where tree roots were pruned and root barriers installed to eliminate the effect of competition on the soybeans, and other areas where tree roots were left intact. Areas within blocks were also separated by zones that received maximal (> 6 hours) and minimal (< 3 hours) amounts of shade each day. Soil moisture and temperature, fractional interception of light, soybean chlorophyll content, and soybean plant height were measured once a month over the growing season, after which soybean plants were harvested for determination of biomass. Statistical analyses were used to evaluate the impacts and relationships among above and below ground competition effects from the trees and on the development of the soybeans. Results found that variation by block, shade, and shade by block was significant ($p \leq 0.1$). While root pruning treatments had a slightly significant positive effect on the soybean development, shading generally had a

greater impact than below ground competition. It appears that shade on the shade-intolerant soybeans was a larger constraint on soybean growth and development than were the effects on below ground competition from adjacent trees. These findings were suggestive of competition impacts in this alley cropping trial, and are biologically and ecologically logical. While definitive conclusions about the soybean-tree interactions require higher and more consistent levels of statistical difference, the results here begin to illustrate these interactions in a long-term developing system that will emerge over several decades.

Influence of Tree Competition by *Pinus taeda* on *Glycine max* in an Alley Cropping Agroforestry System in Eastern North Carolina

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Forestry and Environmental Resources

Raleigh, North Carolina

2012

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DEDICATION

To friends, family, and colleagues. If it wasn't for all of you, I would have never finished.

BIOGRAPHY

Adam Brown was born in Kingsville, Texas on November 11, 1981. His early years were spent moving from one college town to the next following his father who was an academic researcher, then administrator. Love of the outdoors led him to join the Cub Scouts and he continued on all the way through to Eagle Scout. After finishing high school, he enrolled at Lewis & Clark College and majored in Foreign Languages: Russian and Japanese. During his undergraduate studies, he spent 6 months at Kansai Gaidai University near Osaka, Japan and 6 months at Moscow International University in Moscow, Russia. After graduating, he then moved to Japan and spent two years teaching at a public high school. In 2009, Adam decided to go back to school and enrolled at North Carolina State University as a graduate student in the College of Natural Resources. He specialized in agroforestry with a minor in soils. While completing his studies, he spent 6 months in Brazil, earned a graduate certificate in Geographical Information Systems, and became a member of the Xi Sigma Pi forestry honor society. Adam now plans to start a career in help organize and establish agroforestry projects as forms of rural development in the developing world.

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INTRODUCTION

The cultivation of trees and agricultural crops in combination is an ancient practice that has been used by farmers around the world (Nair, 1993). While this practice is now much less common in developed countries, being replaced by mechanized, monocultural farming, it is still widely used in developing countries and gaining acceptance in developed countries. This resurgence of agroforestry in the developed world is due to many factors: prior poor land management, an increasing population, and a need for farmers to diversify their crops to lower inherent risk that comes with monocultures (low prices, disease, droughts, etc.). This has created a need for research into sustainable land use systems to reduce land degradation and diversify land use. Agroforestry is one such system that meets these demands (Nair, 1993; Sanchez, 1995). This thesis examines an agroforestry system in eastern North Carolina and the effect of tree border strips on alleys of agricultural crops.

Agroforestry systems are strongly bound to natural landscape conditions; that is every system will not perform at an optimal level in every environment. It is only through field-based research that new systems can be fully tested and developed for new landscapes (Nair, 1993; Sanchez, 1995; Workman, Bannister, & Nair, 2003). In the southeastern United States, the predominate agroforestry system that has been implemented is silvopastoral (Bendfeldt, Feldhake, & Burger, 2003; Bird, 1998; Dangerfield and Harwell, 1990). There is a need for more research into agroforestry, particularly alley cropping, which has higher potential due to greater commercial interests in both forestry and agriculture (Zinkhan and Mercer, 1997).

This project is an alley cropping trial that was established at the North Carolina Department of Agriculture and Consumer Services (NCDA & CS), and North Carolina State University's Center for Environmental Farming Systems at the Cherry Research Farm in Goldsboro, North Carolina, in January 2007. The design of this project involved three tree species, cherrybark oak (*Quercus pagoda*), loblolly pine *(Pinus taeda),* and longleaf pine (*Pinus palustris*) and two crop alley widths, 12.1 and 24.4 m containing an annual rotation of soybeans *(Glycine max*) and corn (*Zea mays*). The goal is to provide a long-term research and development site that will investigate the potential application and enhancement of this system in the eastern Carolinas.

The focus of this research was to quantify the growth competition effects of strips of loblolly pine on soybeans grown in adjacent alleys. For this project, roots were pruned in certain blocks of loblolly and polyethylene root barriers were installed, while other blocks where left unaltered. The ultimate goal of this project is to determine what positive, or negative, above and below ground effects the trees exhibit on the crop and to suggest how the design of the system be optimized. This agroforestry system is also intended as a demonstration for landowners interested in new approaches to agriculture and farming that are regionally relevant. At the same time, this specific research project allows for management techniques and strategies to be evaluated.

HYPHOTHESIS & OBJECTIVES

The hypothesis of this study was that the loblolly pines will have a significant impact on growth and development of soybeans in an alley cropping system by below ground competition for water and nutrients, and by shade created by the trees. The null hypothesis of this study was that the effect of competition for light and water by loblolly pines on soybean growth and development will not have a significant impact. The objectives of the current study were to evaluate the impact of the roots and shade by loblolly pine on the agricultural environment and growth of soybean by considering the following variables:

- soil temperature
- soil moisture
- chlorophyll content of soybean leaves
- fractional interception of light by the soybean plants
- soybean plant height
- soybean plant biomass
- bean yield

LITERATURE REVIEW

AGROFORESTRY DEFINED

Agroforestry is a collective name for land-use systems and technologies where woody perennials are deliberately grown on the same area as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components that define its potential for success (Lundgren and Raintree, 1982). Furthermore, there are three attributes which, according to Nair (1993), all agroforestry systems possess. These are:

- *Productivity:* The purpose of most agroforestry systems is to maintain or increase the production of the commodity as well as the productivity of the land. Agroforestry can improve productivity in a variety of ways. These include: increasing output of tree products, improving yields of associated crops, reducing the amount of crop system inputs, reducing erosion, and increasing labor efficiency.
- *Sustainability:* By conserving the production potential of the resource base, mainly through the beneficial effects of woody perennials on soils, agroforestry has the potential to achieve and maintain conservation and fertility goals.
- *Adaptability:* New or improved agroforestry technologies should also conform to local farming practices in the area. This allows for easier acceptance by the stake holders and implementation at the new locale.

It is important to emphasize the difference between agroforestry and other terms, such as community forestry and social forestry. Agroforestry is the association of woody perennials and agricultural crops and/or animals for multiple services and products (Nair, 1993). The other terms refer to specific types of tree planting, such as wood lots.

Agroforestry has received modest attention in the United States in recent decades, but that is beginning to change due to a shift in economic, environmental, and social trends. Current land use patterns suggest that there is not only an under-utilization of land-based resources in the United States, but also that current uses of those resources are not totally supported by many segments of society (Garrett and Buck, 1997). There is an interest in a shift from conventional agricultural systems to agroforestry systems. The transition of conventional agricultural systems, and forestry, to an agroforestry approach can be challenging because landowners cannot yet do so with confidence in the economic outcome. Further research and development on these approaches will result in more adopters of these technologies, broader acceptance, and experience leading to confidence in the approach.

There are three principal types of agroforestry systems: agrosilvicultural, silvopastoral, and agrosilvopastoral. Agrosilviculture is the combined production of trees and crops on the same piece of land (King, 1968). The practice improves the land resource by maintaining soil fertility through additions of organic matter from the tree component, decreasing erosion, and increasing productivity. This practice also minimizes destruction of natural forests by cultivators using shifting agricultural practices by providing these farmers with the forest goods that they need while maintaining the productivity of their land. This helps reduce their need to clear more land for agriculture.

Silvopastoral systems are agroforestry systems that are specifically designed for the production of trees, tree products, forage and livestock. As a system, timber and pasture are managed as a single integrated system to produce a timber component while providing a short-term cash flow from the livestock component (Nair, 1993). While all three systems increase wildlife diversity and improve water quality, the forage from silvopastoral systems protects the soil from water and wind erosion, while adding organic matter to improve soil properties. The livestock benefit from the additional forage provided by the trees, in addition to the shade and wind protection that can reduce heat stress or wind-chill on livestock.

Agrosilvopastoral systems are a set of land-use techniques implying the combination of a woody component with livestock and crops on the same site (Nair, 1993; Russo, 2008). These combinations can be simultaneous or alternating in time and space, and contain significant biological interactions (Borel, 1987). The purpose of combining all these components in the same setting is an attempt to achieve sustainability and diversification of outputs. Several authors have analyzed the advantages and disadvantages of agrosilvopastoral systems (Boreal, 1987; King, 1968; Nair, 1993; Russo, 2008). Some of the advantages of such systems are:

- Diversification of products reduces economic risks
- Small farmers, with limited amounts of land, may use the forest to produce fodder for livestock without sacrificing areas dedicated to crops.
- Farmers can obtain economic benefits from fuelwood, timber, posts, and forage, which can be used on the farm for livestock management.
- Between 60 and 70% of plant biomass can be used as feed for the cattle without causing competition with crops for human consumption.
- The animal component can accelerate some aspects of nutrient cycling by returning manure and urine to the soil.

There are also disadvantages to these systems that are important to acknowledge (Russo, 2008). The most important are:

- Compaction of soil by the animal component.
- Agrosilvopastoral systems have been considered a subsistence practice that maintains the poverty status of subsistence farmers.

- Reduced productivity of the tree or crop component due to competition for nutrients and/or water.
- When trees are planted in pasture lands, problems arise due to trampling and browsing by grazing animals.

GLOBAL CONTEXT

Across the entire globe, at one point or another in history, it has been the practice to cultivate tree species with agricultural crops (King, 1987). Beginning long before the Middle Ages, it was common practice in Europe to use "slash and burn" techniques of clear forested land for agricultural production. "Slash and burn" refers to the practice to clearing a forested area, burning the slash to open soil up for cultivation and mineralize the nutrients, and then planting agricultural crops. After a few seasons of production, the land was/is typically abandoned for a host of agronomic reasons, such as loss of topsoil due to erosion, poor fertility, compaction of soil, etc. It was a general custom in Europe, however, to plant tree species before, during, or after the sowing of the agricultural crop (King, 1987). While this system is no longer popular in Europe due to agricultural mechanization, it was still practiced in a few areas in Germany up until the 1920s (King, 1968).

In Southeast Asia, indigenous groups in the Philippines have been practicing a complex type of shifting agriculture in which they clear the forests for rice cultivation but leave selected trees behind. These trees, by the end of the growing season, create a partial canopy that prevents maximal exposure to the sun at a point in the growth cycle of the rice when moisture is more important than sunlight. In addition to this protective role, trees provide food, medicines, construction materials, and cosmetics (Conklin, 1953). In Burma, the "tuangya" system was introduced to the Western world at the beginning of the 19th century. This system was utilized to grow teak in a plantation setting for the British Empire while allowing the producers to grow subsistence crops in the understory. When this system was presented to Sir Dietrich Brandis, the superintendent of forests for Burma, he is alleged to have said that "this, if the people can ever be brought to do it, is likely to become the most efficient way of planting teak" (Blanford, 1958).

In Central and South America, agroforestry has long been practiced by indigenous societies to simulate forest conditions in their farms in order to capture the beneficial effects of forest structures (King, 1987). One of the most commonly implemented agroforestry systems in these areas is the home garden. In this system, dozens of different species are planted together in a multi-tiered system that imitates the structure and diversity of a tropical forest. It is quite common to find these home gardens on plots of land as small as one-tenth of a hectare that contain: coconut (*Cocos nucifera*) or papaya (*Carica papaya*) followed by a lower layer of bananas (*Musa acuminata*), a shrub layer of coffee (*Coffea arabica*) or cacao (*Theobroma cacao*), then a tall ground crop of maize (*Zea mays*) with beans using the maize for stabilization, and finally a ground cover crop such as squash (*Cucurbita spp.*) (Wilken, 1977).

In Nigeria, yams, maize, pumpkins and legumes are typically grown together under a cover of scattered trees (Forde, 1937). The Yoruba, an indigenous group in western Nigeria, have practiced an intensive form of agroforestry in which they mix crops, shrubs, and trees.

They use this system in order to maximize both the extensive amount of labor required to clear and farm the land, and the limited amount of space they typically have for farming. They also claim that it is a means of combating erosion and maintaining soil fertility (Ojo, 1966).

Each of these examples demonstrates the wide geographical scope of agroforestry and its implementation by numerous societies. In the past, trees were established to support agriculture with the ultimate objective being food production. This has changed to include trees as a primary product, as demonstrated by the tuangya system in Burma, and the goals of agroforestry have expanded.

In Brazil, it has been found that growing eucalyptus (*Eucalyptus spp.)* in an agroforestry system instead of in a monoculture is economically and environmentally more sound (Dube et al., 2002). It is also common to find eucalyptus and soybeans in 2-tiered systems in Brazil since the landowners use the annual soybean crop to offset the cost of the establishment of the eucalyptus and to earn an income while waiting to harvest the trees (Coutu et al., 1982).

ALLEY CROPPING DESIGN AND MANAGEMENT

Alley cropping is an agroforestry production system in which trees and/or shrubs are arranged in rows on arable land, with food crops established between the rows (Kang, 1993). Tree rows are typically oriented to minimize shading of the crop species, or if planted on a slope, to minimize erosion. During cropping season, the trees are often cut back and pruned to prevent shading, while using detritus and prunings as green mulch. When the fields are fallow, the trees are allowed to grow freely. Like all agroforestry systems, various site factors must be considered prior to the establishment of the system. Soil characteristics, weed/pest management, water availability, tree/crop species interactions, market demand for trees/crops, landowner's objectives, spatial arrangement of crops and trees, and crop/tree rotation lengths are just some of the factors that must be considered to create a successful alley cropping system. The alley cropping system has been employed using a variety of crops, such as legumes, grains, root crops, and vegetable crops in both mono-culture and inter-cropping systems (Kang et al., 1990). The alley cropping system has also been used with livestock in Africa, with the trees providing shade and forage, and even acting as living fences (Okali and Sumber, 1985).

Over the past three decades, research has shown that it is feasible to sustain and improve crop production on poor soils with the adoption of certain sustainable farming techniques (Nair, 1993). These include the application of the following: (1) the use of farming production systems that minimize soil disturbance and provide adequate ground cover, (2) the use of systems that efficiently cycle nutrients to reduce nutrient loss due to leaching, and (3) the use of chemical inputs, with the periodic input of organic residue, to help improve soil fertility (Kang, 1993). Alley cropping has the potential to meet all three of these criteria, while minimizing production costs and technological needs. Alley cropping integrates the art and wisdom of traditional farmers with 'the efficiency of current science' (Kang, 1993).

Most research and development work on agroforestry is currently being done in

Africa and Southeast Asia through organizations like the World Agroforestry Centre (ICRAF). Little research, until recently, has been done in temperate climate zones, such as the United States. Historically, land managers in these areas have viewed forestry and agriculture as opposing land use alternatives (Garrett and Buck, 1997). The USDA National Agroforestry Center (NAC) was established in 1990 in Nebraska, however, to promote the use of windbreaks and riparian buffers while enhancing water, air, and soil quality.

Forest lands in the southeastern United States have been utilized for almost 300 years, during which time most of this land was under private ownership (USFS, 2001). In a USDA study performed in the late 1980s, it was found that 8 million acres of cropland and pasture in the Upper Coastal Plain and Piedmont Regions yielded lower returns from their present use than they would in timber production (USDA, 1987). Poor management of private forested lands has been all too common, although there is an increasing awareness among landowners about management benefits, an increasing number of consultants to help provide information and services, and promising government incentive programs for farm security and rural investment (Zinkhan and Mercer, 1997). Surveys done in Alabama, Georgia, and Florida suggested that landowners rarely practiced alley cropping or silvopasture, but that riparian forest buffers and windbreaks were the most widely employed forms of agroforestry in these areas (Workman, Bannister, & Nair, 2003). Intensification and diversification of farming systems are seen as ways to maintain production, enhance rural livelihoods, and optimize use of areas remaining in agriculture. With growing interest in agroforestry worldwide, systems involving tree-crop and tree-forage combinations have been suggested as more efficient and economical than those practiced today on marginal crop and pasturelands in the Southeast

(Workman et al., 2003)

Previous research in the southeastern United States has mainly focused on silvopastoral systems (Bendfeldt et al., 2001), while alley cropping research has received little attention despite its potential (Zinkhan and Mercer, 1997). The southeastern United States has this potential due to its diverse climate and landscapes, and the existence of vast areas of forest, crop, and pasturelands that lack sharp demarcations between obviously 'optimal' land uses (Henderson, 1991).

Alley cropping has been researched, predominantly, in the Midwest and has found its greatest popularity in the mid-western and southeastern United States (Jordan, 2004; Jose et al., 2000). In alley cropping systems, the tree rows are spaced according to the biological needs of the crop to be grown between them. The spatial dimensions of the tree rows must be designed to meet a variety of criteria for the average farmer: how well the site should be protected from wind and erosion, what are the management objectives (wood vs. crop), how many trees should be thinned before the final crop of trees will be selected, among others. Even the availability of farming equipment must be considered—alley way widths may need to be designed to accommodate tractors, disks, and combines (Garrett and Buck, 1997). Some concern has been expressed about the quality of wood grown in alley cropping systems, but studies in Missouri, for example, have shown that height, diameter and specific gravity were greater for alley cropped walnut trees than for trees grown under woodlot-like conditions (Cutter and Garrett, 1993).

One of the greatest challenges of agroforestry is managing a system that is extremely diverse and utilizes multiple crops that are growing simultaneously. The most basic systems utilize only two variables, a crop and a tree species. But there exist systems that are designed to incorporate dozens of different species, all having different needs, different growing rates, and different harvest rotations. In alley cropping, the ideal management system has trees and crops growing together without either species having a negative effect on the other (Sanchez, 1995). Studies have shown that when crops and trees come into competition for water resources, however, the crop yields in alley cropping systems are less than those found in monoculture systems (Sanchez, 1995).

There have also been issues with insect and disease management. When perennial species are introduced into annual cropping systems, the control strategy (such as crop rotation) for insect and disease disturbance is replaced by an increased ecological stability created by the introduced perennial species (Schroth et al., 2000). Simply increasing plant diversity, however, does not mean a reduction in pest and disease risk. In fact, the introduction of new species could introduce new pests and diseases that were harbored by the perennial woody species. It has been observed that pest and disease incidences increase at the crop-tree interface due to the humid micro-climate, physical protection of pests by the tree rows, and the reduced pest and disease resistance of competition-stressed crops (Schroth et al., 2000; Rao et al., 2000). Weeds in these systems may respond similarly.

ECOLOGY AND ECONOMICS OF ALLEY CROPPING SYSTEMS

Trees managed in an alley cropping system can provide numerous ecological, social, and economic benefits (Nair, 1993). From an ecological perspective, land management systems that utilize both trees and agricultural crops have greater biological diversity and more diverse plant community structures than monoculture systems (Leakey, 1999). Trees in alley cropping systems have been shown to improve soil structure and reduce erosion, while increasing the availability of nutrients to the annual crop species through additions of organic matter (Buresh and Tian, 1998; Rhoades, 1997). These systems can also support a greater range of fungi, arthropods, bacteria and other components of the soil community, which can increase above ground productivity, although these can also pose management issues through the introduction of pests (Crutsinger et al., 2006). Trees also improve the recycling and reclamation of nutrients in alley cropping systems (Palm, 1995), particularly when leguminous tree species are incorporated into the system since they can capture atmospheric N and return it to the soil as leaf litter (Nair et al., 1984). By incorporating the leaf litter, prunings, and root debris into the soil at the proper time for the crops to take advantage of the nutrient cycling that results from decomposition, the need for external fertilizer additions can be significantly reduced (Palm, 1995). Furthermore, trees can provide shade and fodder for livestock when incorporated into silvopastoral systems, thereby reducing feed costs and reducing heat stress on livestock (Wilson and Kang, 1982). The trees can also access water resources that were previously unavailable due to the greater rooting depth of trees and improve overall soil moisture content by providing shade and lowering the rate of evapo-transpiration (Bremen and Kessler, 1997). There have been studies, though, that have shown that there can be a loss of production in the crop component due to water competition in crop alleys at 12 m, 15 m, and 16.24 m in width (Wanvestraut et al., 2004; Reynolds et al., 2007).

Alley cropping systems can improve annual crop production by providing protection to the agricultural crop, and the implementation of windbreaks and shelter belts have even been found, in some instances, to improve livestock production on pasture lands (Bird, 1998). Trees act as barriers in these systems, protecting the crops and soil from extreme winds and rains, and providing beneficial micro-climates. As the trees mature, however, the increased shade can be detrimental to the growth of the agricultural crop (Thakur and Singh, 2008).

Alley cropping can also contribute to economic diversity and stability. This system allows farmers to diversify their assets while decreasing their dependence on the market prices of fewer agricultural products from a monoculture system. This is especially true when non-timber products are included, such as fruits, nuts, and medicinal species that can be harvested in much shorter periods than timber, where value is not fully realized until the end of the growth rotation (Leakey and Simons, 1998).

Recently, there have also been growing concerns over the long term sustainability of intensive monoculture systems that have resulted in an interest in agroforestry systems in temperate regions. Alley cropping is becoming increasingly popular in the mid-western U.S. since its design addresses both environmental and economic concerns, and the fact that it is adaptable to mechanized agriculture (Garrett and Buck, 1997). Typically, the tree species used in these systems are hardwood species such as assorted oak species *(Quercus spp.),* and pecan *(Carya spp.)* (Jose et al., 2000). Several different agricultural crops have been combined with these systems, such as wheat (*Triticum spp.*), oats (*Avena spp.*), and particularly maize and soybeans.

Among the constraints to agroforestry adoption and productivity, below-ground competition for water has been found to be a major factor causing yield reductions in alley cropping systems in the tropics (Ong and Leakey, 1999; Singh et al., 1989), while above-ground competition has been observed as the most limiting factor in temperate alley cropping systems (Jose et al., 2000). When plant growth is not limited by water or nutrients, biomass production is then limited by the amount of radiant energy the foliage can intercept (Jose et al., 2004). When considering the effect of shading by the trees on the crop components, there are conflicting studies. Several studies have reported, however, that shading had little to no effect, or in some cases, positive effects on crop growth in tropical agroforestry (Lin et al., 1999; Leihner et al., 1996; Gillespie et al., 2000) while other studies have shown the opposite (Thakur and Singh, 2008).

METHODS

GEOGRAPHICAL INFORMATION

WAYNE COUNTY

Wayne County covers 1,435 square km (554 square mi) of eastern North Carolina found in the upper Coastal Plain. Starting from the eastern section of the county and going west, the elevation is 37 m (120 ft), rising to 44 m (145 ft). The principal city in Wayne County is Goldsboro, which lies along the Neuse River. The current project is located on the state-owned Cherry Research Farm, which is in the portion of Wayne County near Goldsboro and the Neuse River (35°20'N lat. and 077°58'W). Average temperature is 16.23 ºC (61.2 ºF), with average annual low and high temperatures falling between 0.5 and 33 ºC (33 – 92 ºF), and average yearly precipitation is 1,266 mm (50 in) and growing season rainfall (June to September) is 508 mm (20 in) (State Climate Office of North Carolina; Cherry Research Station, Goldsboro, North Carolina).

In 2011, when the current study was conducted, growing season rainfall (June to September) totaled 484.7 mm and mean temperature during this period was 25.8°C (State Climate Office of North Carolina, Cherry Research Station; Goldsboro, North Carolina). While June only had 23.4 mm of rainfall, these drought-like conditions were alleviated over the next 2 months with 422.2 mm of rainfall (Figure 1). Air temperature varied from an average daily temperature of 27.8°C in July to 22.8°C in September (Figure 2).

CHERRY RESEARCH FARM & THE CENTER FOR ENVIRONMENTAL FARMING SYSTEMS

The Cherry Research Farm is located on 908 ha (2,245 acres) that was originally a source of food for the Cherry Hospital; which is a state-owned mental health institution. The patients would work the farm as a form of therapy and also help support the hospital financially. In 1974, the farm was transferred to the N.C. Department of Agriculture and Consumer Services (NCDA&CS) and in the mid-1980's the farm was transferred to NCDA & CS's Research Stations Division and began to focus on agricultural research.

FIELD RESEARCH SITE DESCRIPTION AND SITE PREPARATION

The research site is a10 ha (25 acre) agriculture field that had been in corn and soybean production for several years, and in cultivation for a number of decades or longer. The research site is approximately 105 m (345 ft) wide and 667 m (2,188 ft) long, running northwest to southeast. The southeast edge of the field borders the Neuse River and swamps comprised of cypress groves, and the northeastern edge borders a tree-lined ditch for drainage. The field is highly variable in soil types. The USDA soil survey of 1974 (http://soils.usda.gov/survey) states that the field site is composed of four soil series: Lakeland sand (61.4% of total field ha), Coxville loam (32.2% of total field ha), Chewacla loam (4.1% of total field ha), and Leaf loam (2.3% of total field ha) (Figure 3). A subsequent on-farm soil survey from 1995 suggests as many as 9 soil series present on the site (Paul Mueller, Joseph Kleiss, personal communication, April, 2012, NCSU). The variation in this field is most likely due to the fact that the field is located in an ox-bow of the Neuse River and experiences periodic flooding that comes from the upper part of the Neuse River, north of the field to the lower boundary of the field and into a southern section of the Neuse River (Figure 4).

The Lakeland soil series consists of deep, maximally drained, permeable soils found on uplands which are formed in thick beds of eolian or marine deposits. These sandy soils tend to be low in natural fertility and lack organic matter. They are also prone to drought due to the deep, maximally drained sands that make up this soil. Crops planted in these soils tend to respond poorly to lime and fertilizer due to leaching, droughtiness, low fertility, and erosion. The Natural Resource Conservation Service (http://soils.usda.gov/survey) does not consider these soils to be prime farm land and recommends that they be used for pasture and typical agricultural crops such soybeans, corn, etc. The Lakeland series is characterized as having an annual productivity of 1.36 metric ton/ha (20 bu/ac) of soybeans and a loblolly pine site index of 21 m (70 ft) at a base age of 50 years (Barnhill et al., 1974).

According to the 1995 soil survey performed on the research site, the area occupied by the Lakeland soil series is actually comprised of three other soil series: Tarboro, Conetoe, and Seabrook. The Tarboro soil series is composed of very deep, somewhat excessively drained, rapidly permeable soils that occur in stream terraces and marine terraces along the Coastal Plain, and are formed from alluvium and marine deposits. These soils are used typically for agriculture and forestry with an annual productivity of 1.36 metric ton/ha (20 bu/ac) of soybeans and a loblolly pine site index of 21 m (71 ft) at a base age of 50 years (http://soils.usda.gov/survey). The Conetoe soil series is comprised of very deep, well drained soils that have moderately rapid permeability and slow surface runoff. The parent material for these soils is loamy, sandy fluvial and marine sediments, occurring along stream and marine terraces found on the Coastal Plain. These soils are used mostly for cropland and pasture, but can be used for woodlands as well. They are subject to droughtiness and soil blowing which can limit crop yield and increase seedling mortality. The annual productivity for these soils is 1.7 metric tons/ha (25 bu/ac) of soybeans and a loblolly pine site index of 27 m (89 ft) at a base age of 50 years (http://soils.usda.gov/survey). The Seabrook series is composed of very deep, moderately well drained soils with rapid permeability and slow surface runoff. The parent material of these soils is comprised of sandy marine and fluvial sediments found on terraces in the Coastal Plain. These soils are typically used for cropland and woodlands, but are somewhat limited due to wetness and leaching, along with a low available water capacity. These soils have an annual productivity of 2 metric tons/ha (30 bu/ac) and a loblolly pine site index of 25 m (81 ft) at a base age of 50 years (http://soils.usda.gov/survey).

The Coxville series is composed of poorly drained soils formed from stream sediments on terraces, and in slight depressions between streams. These soils make poor farmland due to surface ponding and a seasonal high water table that is at the surface. They also have some natural fertility but are low in organic matter. When the soil is artificially drained, however, it becomes well suited for corn and soybeans. The generalized annual productivity of this series is 3 metric tons/ha (48 bu/ac) of soybeans, while loblolly pines tend to respond well when grown on these soils with a site index of 27 m (90 ft) at a base age of 50 years (Barnhill et al., 1974).

The Chewacla series are somewhat poorly drained, nearly level soils on flood plains that are formed from recent alluvium. The farming potential for this series is limited due to very frequent flooding, a seasonal high water table of 0 - 305 mm (0 – 12 in) below the surface, and low natural fertility and organic matter content (http://soils.usda.gov/survey). With fertilization and proper drainage, however, these soils have the potential to be highly productive with a general annual productivity of 2.4 metric tons/ha (40 bu/ac) of soybeans, and a loblolly pine site index of 30.5 m (100 ft) at a base age of 50 years (Barnhill et al., 1974).

The Leaf series are formed in clayey alluvial and fluvial sediments found on flood plains, and consist of very deep, poorly drained, slowly permeable soils (http://soils.usda.gov/survey). Theses soils have some natural fertility but are low in organic matter content. Most of the acreage for this series is used for forestry and pasture due to the high seasonal water table, surface ponding, and infrequent flooding. The generalized annual productivity for soybeans is 2.1 metric ton/ha (35 bu/ac) and the loblolly pine site index is 27 m (90 ft) but only where adequate surface drainage is available (Barnhill et al., 1974). The soils are arrayed from northwest to southeast, following the slope of the land (the southeast being the bottom of the slope). At the top half of the field, the sandy soils, such as the Lakeland and Chewacla series, quickly give way to soils composed of more silt and clay, like the Coxville and Leaf series (http://soils.usda.gov/survey).

The agroforestry project was initiated in January 2007, on the previously described site. Trees were planted by block between January 12-15, 2007, by an assortment of students, professors, and prison laborers. All the tree seedlings came from the North

Carolina Division of Forest Resources, Claridge State Forest Tree Nursery in Goldsboro, NC. The loblolly pines were planted as 1-0 bare root seedlings grown from publicly available, genetically improved seed. The longleaf pines were planted as 1-0 containerized seedlings grown from seed that originated in Bladen County, North Carolina. The cherrybark oaks were planted as 1-0 bare root seedlings with seed that came from Pee Dee River basin in upper South Carolina.

An attempt was made to break up the hard pan that was present under the plow layer in the field by tractor ripping. However, the field was too wet and the operation was discontinued after 1/3 of the field had been ripped. The ripping was restarted after the trees were planted in April, but this proved impossible and was abandoned. This partial ripping was presumed to have minimal effects on the study since it uniformly crossed 1/3 of the field lengthwise, thereby equally crossing all 5 replications. The trees were planted between the rip lines where they occurred, and thus during the first year or two of this study there would have been little effect of this ripping on the root systems of the seedlings 0.76 m away from the nearest rip. A second attempt to overcome the hard pan for each tree was to use a 21 cm (9 in) diameter auger drill to establish each planting hole. However, this operation was also abandoned due to the difficulty and time required to drill each hole and the uncertainty of actually penetrating the hard pan. This drilling was only attempted in one corner of Block 1, but was filled after the attempt was terminated, and the trees were planted away from any of the holes actually made. For more information on the history of the research site following the establishment of the agroforestry trial in January 2007, see Appendix C. For more information on the research site prior to the establishment of the agroforestry trial, see Appendix D.

OVERALL EXPERIMENTAL DESIGN

The site was designed to manage both annual agriculture crops as well as long-term tree crops. The agriculture production was set up in an annual soybean and corn rotation. The overall experimental design was a split block with five replications. Each block contained four crop alleys, two with 12 m widths and two with 24 m widths, and the three tree species used were: *Pinus taeda* (loblolly pine), *Pinus palustris* (longleaf pine), and *Quercus pagoda* (cherrybark oak). Loblolly pine is a tree species that is adaptable to various soil types which makes it ideal for the field site in this experiment. Also, loblolly pine was chosen due to the fact it is the regional and commercial importance as a timber species in the southeastern United States (Jokela et al., 2004). This makes loblolly pine desirable to many landowners interested in establishing an agroforestry system on their lands. The longleaf pine species once occupied over 30 million ha in the southeastern United States at the time of European discovery (Van Lear et al., 2005). Most of that range was lost by 1850 due to commercial extirpation of the species for naval stores (Frost 2006). Longleaf pine remains a commercial desirable species with a unique ecology, however, which is why it was selected for this study. In addition, longleaf pine is suitable for sandy soils which compose a large portion of the field plot. Cherrybark oak was selected for its fast growth rate and for its high value as a hardwood species used in furniture making, construction, and veneer.

The field was blocked, from northwest to southeast, to account for the main gradient of soil variation and slope (Figure 2). Each block was 105 m (345 ft) wide and 128 m (420 ft) long with 1.5 m (5 ft) buffers established around the edges of the field. Each block was further subdivided into annual agricultural crop alleys and bordered by tree plots. The crop alleys were of two different dimensions, 12 m (40 ft) wide by 128 m long, and 24 m (80 ft) wide by 128 m long. Tree plots were 6 m (20 ft) wide and 128 m long (Figure 4).

The tree plots were established linearly both along the edges of the field and in-between the crop alleys, always arrayed northwest to southeast. The tree plots were further divided into thirds lengthwise measuring 6 m (20 ft) by 42 m (140 ft), with each subplot representing a different species (loblolly, longleaf or cherrybark oak (Figure 5). Trees were planted in a triple row design within the plots at 1.5 m by 2 m (5 ft by 7 ft) spacing. There were 4.5 m (15 ft) of unplanted areas running across the width of the field, between each block, and along field boundaries, for farming equipment access.

2011 ROOT BARRIER SITE PREPARATION

On May 9, the agroforestry crop alleys was disked for planting and on May 27 and June 1, slit trenches were made 45.72 cm (18 in) deep by 21.3 m (70 ft) long on 2 out of every 4 quadrants in each block. Each trench was made 1.23 m (4 ft) from the tree rows with a small tractor mounting a trencher on the back.

On June 6, the field plot was disked again and field conditioned with a Taylor field conditioner. On June 17, Asgrow 5605 soybeans were planted at 67.2 kg/ha (60 lb/ac) at

76.2 cm (30 in) row spacings with a JD 1700 six-row planter. For herbicide treatment, Round-up was sprayed on June 29 at 1.75 L/ha (24 oz/ac) with JD hi-cycle, Flexstar GT at 4 L/ha (3.5 pt/ac), and methylated seed oil at 1.17 L/ha (1 pt/ac) in July.

ROOT PRUNING STUDY

For this study only the 24 m alleys between strips of loblolly pine in each of four blocks were selected. Each block contained two 24 m alleys bordered by areas of loblolly pine. Each of these areas was subdivided into quadrants, giving each block four quadrants. Out of the four quadrants in each block, two were selected to receive a root pruning treatment to test whether competition for water and nutrients adversely affected crop growth. Because four out of the five blocks had the two 24 m areas established next to each other, it was necessary to stagger the treatments to insure that none of the trees had their roots pruned on both sides (Figure 6).

The root pruning treatments were made 1.2 m (4 ft) from the tree strips for a distance of 21 m (70 ft) to a depth of 45.72 cm (18 in). The basis for this design was that crop planting occurred 1.2 to 1.5 m from the tree strips since the tractors had to avoid breaking off the tree limbs. The length of these trenches represents half the length of the alleys, 42 m (140 ft). The depth of the trenches was based on the depth to the hard pan. Because the hard pan was found to be at 45.72 cm (18 in), the roots of the soybean crop were unlikely to penetrate below this depth and the roots of the loblolly pines were unlikely to extent into this layer. In addition, root barriers were installed in the trenches by inserting 8mm plastic sheeting measuring 101.6 cm (40 in) by 42 m (140 ft). Each sheet was then folded in half lengthwise to double its thickness and making each strip 50.8 cm (20 in) by 21 m (70 ft). After each trench was dug, the plastic sheets were inserted, weighted down with soil, then the trenches were refilled with the removed earth, leaving 5.08 cm (2 in) of plastic above ground. A total of 20 root pruning trenches were established on the field plot.

For sampling purposes, transects were established in each of the loblolly pine triple-row linear subplots that were separated by 24 m wide cropping areas planted with soybeans in 2007. Each subplot was divided in half by length, and two transects established that run from one tree strip to the next through the soybeans, each being 1.5 m wide (5 ft) and 24 m long, for a total of four transects in each block (Figure 4). Each transect location was chosen where the trees were at the average mean height of all four blocks (3 m), with the most foliage, and largest diameter, with at least a 5 m (15 ft) buffer to the edge of each tree subplot.

SOIL MOISTURE AND TEMPERATURE

Soil moisture and temperature were recorded along established transects that ran from across the alleys, taking measurements from every other row (16 samples total for each transect). The mean soil moisture was measured using a Theta Probe moisture meter (Delta-T Devices Ltd.; Cambridge, United Kingdom) that recorded the percent volumetric soil moisture (%mV). The device is equipped with four 6.35 cm (2.5 in) metal probes at the end of a plastic pipe casing holding the electronics of the probe, which are inserted into the ground to their full length. Soil temperature was recorded using a digital thermometer, calibrated beforehand in hot and freezing water, at 7.62 cm (3 in) depth. Each measurement was taken at the base of the soybean plants along the transects, as well as at the crop tree interface and in the tree strips themselves. Samples were then collected on July 15, August 16, and September 13. On each of these days, soil moisture measurements were collected from 9 AM to 11 AM while soil temperature measurements were taken from 11 AM to 1 PM. All data on rainfall amounts were collected from the Goldsboro weather station for the 2011 growing season.

PHOTOSYNTHETICALLY ACTIVE RADIATION INTERCEPTION OF SOYBEAN CANOPY

PAR (photosynthetically active radiation) is considered to be the radiation in the 400 to 700 nanometer waveband. It represents the portion of the electromagnetic spectrum that plants can use for photosynthesis. Dry matter production of a plant canopy is related to the amount of PAR intercepted by the canopy. By taking measurements both above and below the canopy, the fraction of transmitted PAR can be found. Dry matter production is a product of conversion efficiency, flux density of incident radiation intercepted by the crop, and the fractional absorption of radiation. By monitoring the flux density of incident radiation and the fractional absorption over the period of growth for the soybeans, and the dry matter is measured at harvest, the conversion efficiency can be determined. The results of root pruning treatments can be interpreted in terms of their effects on the conversion efficiency and fractional absorption.

To measure fractional absorption, the ceptometer was placed above the canopy, leveled, and then a reading was taken with the sensor pointing skyward. The ceptometer was then placed below the canopy making sure to place it below all of the leaves. Since the canopies had a row structure, it was important that samples show no favor of between-row and within-row areas. Therefore the probe was placed diagonally and readings collected to get a representative sample. Samples were collected on June 14, July 17, August 16, and September 14. Each sampling day had clear skies as to not effect measurements. Sixteen samples were collected from each transect, totaling 64 samples from each block.

SOYBEAN CHLOROPHYLL CONTENT

Chlorophyll content was measured using a Chlorophyll Meter SPAD-502 (Konica Minolta Sensing, Inc.; Ramsey, New Jersey) to determine the amount present in the soybean leaves. The values are calculated based on the amount of light transmitted by the leaf in two wavelength regions in which the absorbance of chlorophyll is different. The amount of chlorophyll present in plant leaves can serve as an indicator of the overall health and condition of the plant itself.

The healthiest leaves from the upper third of the plant were selected for measurement, taking care to avoid measurements on extremely thick areas, such as the veins of a leaf. Measurements were taken along the predefined transects, using plants from every other row. Data was gathered on July 16, August 17, and September 12. Sixteen samples were selected from each transect, yielding a total of 64 samples for each block.

SOYBEAN ANALYSIS

The soybean crop was measured for height, dry matter production, mass of beans produced. Height measurements were taken when the plants had reached the R5 stage of beginning seed development (Figure 7). This stage in the growth of the plants is characterized by rapid seed development, with nutrient accumulation and dry matter distribution shifting from vegetative development toward the seed. It is also at this stage that plants have attained their maximum height, node number, and total leaf area. Plants were selected along the predefined transects, using every other row to yield 16 samples per transect. For dry matter and bean mass per plant measurements, samples were collected on October 24. Three soybean plants were collected from the eight rows closest to the tree rows, and then samples were collected from every third row in between. This created 24 samples per transect, or 96 samples per block. Each sample was then dried in an oven at 70° C for 24 hours. Then the beans were measured for mass with the stem measured separately. After the data for each of the three plants were recorded, the totals were averaged to produce a mean bean mass (pods and beans) and stem mass for each sample.

WEED ANALYSIS

While this analysis was planned, it was not completed. This was due to the fact that the soybeans were twice sprayed with *glyphosate* and weeds only appeared near the end of the growing season. Also, the presence of the weeds was sporadic among the treatments and difficult to quantify their effect on the transects.

DEER BROWSING

It was found half way through the project that deer were entering the field plot and browsing the soybeans. This amount of browsing was recorded due to its effect on the growth and production of the soybean plants. Deer browsing was found to be limited across the study site with the exception of areas within fifth block therefore this analysis was not included. This block was located at the lowest end of the site, closest to the adjacent natural wooded areas, and where loblolly pines had grown the tallest (Figure 2, 3; Table 1). White-tailed deer (*Odocoileus virginianus*) are well known to cause damage to soybean crops in the southeastern United States and especially at field edges and in areas that are bordered by forest (Garrison and Lewis, 1987). This was the case in the current study and browsing was mostly restricted to the soybean rows closest to the tree strips. The effect of the deer browsing in this one replication does suggest that the tree strips could be havens for deer and, over time as the trees grow, allow them to expand their browsing territory. The role of deer browsing warrants further study.

SHADE

The effect of shade created by the loblolly pines on the soybean crop was determined by calculating the sun's position and the shadow cast by the trees for the location of this research. Since these measurements would be compared against the production and growth of the crops, the date used for the sun's position was chosen based on the point when the soybean plants would have reached greatest development, but before desiccation would initiate. This was determined to be 75 days after germination, at the R5.5 stage of development (Figure 5). With the soybeans having been planted on June 17, and then emerging approximately a week later, the date chosen for shade calculations was September 7. The length of the tree shadows was determined by taking the average tree height of the loblolly pines in each replication (Table 1) and multiplying it by the shadow length multiplier (Swain, 2009). The 4 rows of soybeans closest to the southern side of the tree rows were designated as "maximally shaded" as they received 6 hours or more shade a day. The 4 soybean rows closest to the northern side of the crop alleys were labeled as "minimally shaded" as they received 3 hours or less shade a day, and all early in the morning. Variables measured from these rows (soybean rows 1-4 and 13-16) were compared to each other by root pruning treatments, and by extent of shading.

STATISTICAL ANALYSIS

Data analyses, except correlations, were performed using the mixed linear model procedure of SAS (PROC MIXED) (SAS Institute Inc., 2009). Correlations between data and plant biomass/production were tested using Pearson's correlation coefficients (PROC CORR) (SAS Institute Inc., 2009). The data was analyzed to determine statistical relationships between soybean height, soybean production, temperature, moisture, weed coverage, PAR, deer browsing, and chlorophyll in both unpruned and pruned root treatments.

Pearson's' correlation coefficients were used to find relationships in the data different blocks. Pearson's' correlation coefficients were also used to find relationships between soybean height/production and climactic data for each treatment. P values greater than 0.25 were treated as suggestive of significant or interesting results, while recognizing that P values greater than 0.1 are generally not considered significant as recommended by Quinn and Keough (2002).

A few data records were omitted from the final analysis because they were orders of magnitude different than reasonable. The analyses were run with and without these omissions and results indicated no significant differences in the statistical results.

The fifth block was removed from analysis due to several reasons. Deer browsing had a significant effect only on this replication. While some deer browsing was found in other replications, it was sporadic and its effect was negligible. Furthermore, the average height of the trees in this replication was significantly larger than those of the other 4 replications; 4.8 m vs. 2.8 m (15.7 ft vs. 9.3 ft). Due to these issues that exist on only the fifth block, it was decided not to use the data gathered from this replication as it would have a significant uncontrolled effect on the final analysis of the data, making comparisons unmeaningful.

RESULTS

OVERALL ANOVA ANALYSIS OF SHADE, ROOT PRUNING TREATMENTS, BLOCKING, AND INTERACTIONS

In these analyses, the effects of root pruning, shading, blocking, and their interactions with each other were examined for significance while using tree height as a covariate. A significance of $p \leq 0.1$ was used when performing these tests, while values of $p \leq 0.25$ were considered values of interest.

SOYBEAN HEIGHT

When examining the soybean plant height for the month of July, no significance was found for any source of variation (Table 2). For the month of August, there was significance found in the block effect (p=0.0027) and shading by block effect (p=0.0108) with significance values of interest in shading (p=0.1243) and pruning by block (p=0.1517) effects (Table 3). Again in September, significance was found in the block (p=0.0260) and shading by block (p=0.0108) effects with significant values of interest in shading (p=0.1474) and pruning by block (p=0.2390) effects (Table 4).

TOTAL SOYBEAN BIOMASS

After examining total soybean biomass, variation due to blocking (p=<.0001), pruning (p=0.0109), pruning by block (p=0.0072), shading (p=0.0002), and shading by block (p=0.0555) were found to be significant (Table 5). During analysis of bean pod mass, again, blocking (p=<.0001), pruning (p=0.0063), pruning by block (p=0.0013), shading (p=<.0001), and shading by block (p=0.0804) were found to be significant (Table 6). However, when examining stem mass, only shading (p=0.0154) and shading by block (p=0.0518) were significant while blocking (p=0.1004) and pruning (p=0.1253) were only values of interest (Table 7).

SOIL MOISTURE

Variation by blocking (p=<.0001), pruning by block (p=0.0003), shading (p=<.0001), and pruning by shading (p=0.0719) were significant for the month of July while pruning (p=0.1257) was a value of interest (Table 8). For the month of August, variation in soil moisture was attributed to blocking (p=<.0001) and shading (p=0.0287), but pruning by block (p=0.1295) and shading by block (p=0.1443) should also be given attention (Table 9). In September, blocking (p=<.0001) and shading by block (p=0.0034) were significant with pruning by block (p=0.1553) being a value of interest (Table 10).

SOIL TEMPERATURE

Analysis of soil temperature for July revealed variation of significance in blocking (p=<.0001), pruning by block (p=0.0014), shading by block (p=0.0464) (Table 11). Furthermore shading proved to be a source of interest due to its level of significance (p=0.1037). For August, variation in soil temperature was significant in blocking (p=<.0001), shading (p=0.0737), shading by blocking (p=0.0332), and pruning by shading by blocking (p=0.0744) (Table 12). In September, blocking (p=<.0001), shading by block (p=0.0841), and pruning by shading by block (p=0.0125) were significant with pruning by block (p=0.1511) be a value of interest (Table 13).

FRACTIONAL INTERCEPTION OF LIGHT (FIL)

Examination of FIL in July demonstrated that shading (p=0.0612) and shading by block (p=0.0779) were significant while blocking (p=0.1251) and pruning by shading by block (p=0.1817) were only values of interest (Table 14). August was somewhat different in that variation by block (p=0.0220), pruning (p=0.0065), shading by block (p=0.0270), and pruning by shading by block (p=0.0865) were all significant with shading (p=0.1513) being a value of interest (Table 15). In September, variation by block (p=0.0041), pruning by block (p=0.0518), shading (p=<.0001), and shading by block (p=0.0034) were all significant with pruning (p=0.109) being a value of interest (Table 16).

CHLOROPHYLL CONTENT

For August, the only sources of variation that were significant were pruning by shading (p=0.0261) and pruning by shading by block (p=0.0857) (Table 17). In September, variation by block (p=0.0062), pruning by block (p=0.0761), and pruning by shading (0.0849) were significant with pruning by shading by block (p=0.1568) was a value of interest (Table 18).

ROOT PRUNING EFFECTS ON SOYBEANS AND ENVIRONMENT WITHOUT CONSIDERATION OF SHADE

SOYBEAN HEIGHT

In July, soybean plant heights across the four replications were highly variable. The means for both root treatments were almost the same with almost no difference in standard deviation. When examining only the eight rows closest to the tree lines (rows 1-4, 13-16), the mean height of the soybean plants in areas that had not received root pruning treatments areas was slightly higher. The difference was only 0.05 cm, however, and therefore negligible. There was only minimal variation in the plant height means between the two treatments across transects (Table 19).

In the month of August, plant heights were slightly statistically different for each treatment. Plant height was greatest in areas where root pruning treatments had been performed. Among the rows closest to the tree line, plant height was slightly greater for non-pruned areas. The variation in plant height means across transects between the two treatments ranged from 66.52 cm to 66.83 cm, and 65.23 cm to 66.27 cm for the rows closest to the tree strips (Table 19).

In September, soybean plant height remained only slightly different between both treatments. Mean plant height was greatest in areas that had not received the root pruning treatments, but the difference between treatments was only 0.76 cm (Table 19). The same was true among the rows closest to the trees; soybean height was greater in the areas that had not been pruned. The variation in plant height means across transects among the two treatments ranged from 72.01 cm to 72.77 cm, and 70.74 cm to 72.11 cm for the eight rows closest to the tree strips (Table 19).

TOTAL MASS OF SOYBEAN PLANTS

Mean total mass of soybean plants in each treatment was similar in all replications. Total mass in areas that received the root pruning treatments were slightly greater than those in non-pruned areas. The same was true in the rows closest to the tree strips in areas that had been pruned. Variation in total mass never exceeded more than 3 g per soybean plant (Table 19).

BEAN MASS

Mean bean mass for soybean plants was similar among treatments. Bean mass across the entire transect and in the rows closest to the tree strips was greater in areas that had been pruned. The variation in mean bean mass ranged from 14.16 g to 16.45 g per soybean plant across transects, and 12.61 g to 14.42 g per soybean plant in rows closest to the tree line (Table 19).

STEM MASS

Mean stem mass were comparable between both root treatments. Stem mass was greater in areas that had received the pruning treatment, and the same was true when analyzing the rows closest to each tree strip. Variation in mean stem mass ranged from 5.11 g to 5.78 g per soybean plant across transects, and 4.88 g to 5.04 g soybean plant in rows closest to the tree line (Table 19).

SOIL TEMPERATURE

In July, soil temperature means across the four replications were similar for each root treatment tested. Soil temperature was greatest in areas where no root pruning treatments had been performed. The variation in soil temperature means across transects between the two treatments ranged from 32.23°C to 32.24°C, and 32.12°C to 32.29°C (Table 20).

There was little correlation between soybean plant height and soil temperature in the month of July. In areas that received root pruning treatments, there was no significance (p=0.615) or correlation (r=0.046) between July soil temperature and plant height (Table 21). In areas that had not been root pruned, there was no significance (p=0.644) or correlation (r=0.043) between July soil temperature and plant height (Table 4).

When analyzing the 8 soybean rows closest to the tree line in each transect (4 on each side), no significance (p=0.898) or correlation (r=0.017) was found between July soil temperature and plant height in areas that had received the root pruning treatment (Table 21). Similar results were found in areas that had not received pruning treatments; there was no significance (p=0.196) or correlation (r=0.178) between plant height and July soil temperature (Table 21).

In August, soil temperature was similar in all four replications for each treatment. Soil temperature was greatest in areas that did not receive the root pruning treatment. Also, soil temperatures were found to be minutely lower in the rows closest to the tree line in the areas that received the pruning treatments. Variation in soil temperatures means across transects for August ranged from 28.99°C to 29.11°C, and 29.03°C to 29.15°C for rows nearest the tree strips (Table 3).

In August, there was moderate correlation between soybean plant height and soil temperature. In areas that received root pruning treatments, there was significant (p=<.0001) and moderately strong, negative correlation (r= -0.512) between August soil temperature and plant height (Table 21). In areas that had not been root pruned, there was also significant (p=<.0001) and moderately strong, negative correlation (r= -0.606) between August soil temperature and plant height (Table 21).

When analyzing the 8 rows closest to the tree lines in each transect (4 on each side), significant (p=0.0045) and moderate, negative correlation (r= -0.364) was found between August soil temperature and plant height in areas that had received the root pruning treatment (Table 21). In areas that had not received pruning treatments, there was significant (p=0.0002) and moderately strong, negative correlation (r= -.487) between soybean plant height and August soil temperature (Table 21).

During the month of September, soil temperatures were similar across all treatments in all replications. Unlike prior months, soil temperatures were greatest across transects that did receive root pruning treatments. When analyzing the rows closest to the tree lines, temperatures were almost the same in both the root pruned areas and non-pruned areas. Variation in soil temperature means across transects ranged from 23.28°C to 23.33°C, and 23.31°C to 23.33°C among rows closest to the tree line (Table 20).

In September, there was little correlation between soybean plant height and soil temperature. In areas that received root pruning treatments, there was significant (p=0.0134) and weak, negative correlation (r= -0.222) between September soil temperature and plant height (Table 21). In areas that had not been root pruned, there was moderately significant (p=0.061) and weak, negative correlation (r= -0.173) between September soil temperature and plant height (Table 21).

When analyzing the 8 soybean rows closest to the tree lines in each transect (4 on each side), no significance (p=0.80) or correlation (r= -0.033) was found between September soil temperature and soybean plant height in areas that had received the root pruning treatment (Table 21). In areas that had not received pruning treatments, there was also no significance (p=0.79) or correlation (r= -.036) between plant height and September soil temperature (Table 21).

There was significant (p=0.0006) and weak-to-moderate, negative correlation (r= -0.306) between September soil temperature and total mass of the soybean plants in areas that had been root pruned (Table 22). In areas that had not received the pruning treatments, there was significant (p=0.025) and weak, negative correlation (r= -0.206) between soil temperature and total mass of the plants (Table 22).

Among the rows closest to the tree strips, there was moderate significance (p=0.106) and weak, negative correlation (r= -0.212) between September soil temperature and total mass in areas that received the root pruning (Table 22). This was also true in areas that had not received pruning; there was weak significance (p=0.181) and very weak, negative correlation (r= -0.186) between soil temperature and total mass (Table 22).

There was significant (p=0.0098) and weak, negative correlation (r= -0.232) between September soil temperature and stem mass of the soybean plants in areas that had been pruned (Table 22). In areas that had not received the pruning treatments, there was moderately significant (p=0.085) and very weak, negative correlation (r= -0.159) between soil temperature and stem mass of the plants (Table 22).

In the soybean rows closest to the tree strips, there was weak significance (p=0.20) and very weak, negative correlation (r= -0.169) between September soil temperature and stem mass in areas that received the root pruning (Table 22). In areas that had not received root prunings, there was no significance (p=0.489) or correlation (r= -0.097) between soil temperature and stem mass (Table 22).

There was significant (p=0.0006) and weak-to-moderate, negative correlation (r= -0.304) between September soil temperature and bean mass of the soybean plants in areas that had been root pruned (Table 22). In areas that had not received the pruning treatments, there was significance (p=0.0232) but no correlation (r= -0.209) between soil temperature and bean mass of the plants (Table 22).

Among the soybean rows closest to the tree strips, there was moderate significance (p=0.095) but no correlation (r= -0.218) between September soil temperature and bean mass in areas that received the root pruning (Table 22). This was also true in areas that had not received root pruning; there was moderately significant (p=0.126) and very weak, negative correlation (r= -0.212) between soil temperature and bean mass (Table 22).

SOIL MOISTURE

Soil moisture means across all root treatments and replications never varied more than 2% in the month of July. Soil moisture was greater in the areas that received root pruning treatments. This was true across the entire transect and the rows closest to the tree line. Variations in soil moisture means ranged from 12.87% to 14.40% (Table 20).

In July, there was little correlation between soybean plant height and soil moisture. In areas that received root pruning treatments, there was significant (p=0.0775), but no correlation (r=0.162) between July soil moisture and plant height (Table 21). In areas that had not been pruned, there was no significance (p=0.715) or correlation (r= -0.034) between July soil moisture and plant height (Table 21).

When analyzing the 8 soybean rows closest to the tree line in each transect (4 on each side), significant (p=0.045) and very weak correlation (r=0.264) was found between July soil moisture and soybean plant height in areas that had received the root pruning treatment (Table 21). In areas that had not received pruning treatments, there was no significance (p=0.473) or correlation (r= -0.099) between plant height and July soil moisture (Table 21).

In the month of August, soil moisture means were similar for all root treatments in all replications. While soil moisture was greatest in areas that had not received the root pruning treatments, the difference in soil moisture means was never more than 0.05% even in the rows closest to the tree line. Soil moisture means for August were 8.69% root pruned areas and 8.74% in areas that did not receive root pruning treatments (Table 20).

There was very little correlation between soybean plant height and soil moisture for the month of August. In areas that received root pruning treatments, there was significant (p=0.021) and no correlation (r= 0.207) between August soil moisture and plant height (Table 21). In areas that had not been pruned, there was significant (p=0.059) and very weak correlation (r= 0.174) between August soil moisture and plant height (Table 21).

When analyzing the 8 soybean rows closest to the tree lines in each transect (4 on each side), no significance (p=0.524) or correlation (r= 0.084) was found between August soil moisture and plant height areas that had received the root pruning treatment (Table 21). In areas that had not received pruning treatments, there was no significance (p=0.977) or correlation (r= -0.003) between soybean plant height and August soil moisture (Table 21).

Soil moisture readings were similar in all root treatments for the month of September. Soil moisture was greatest in areas that had received root pruning treatments, but the difference was less than 2% difference between the treatments. Soil moisture means were 11.87% non-root pruned areas and 12.29% in root pruned areas (Table 20).

In September, there was some correlation between soybean plant height and soil moisture. In areas that received root pruning treatments, there was significance (p=<.0001) but no correlation (r=0.389) between September soil moisture and plant height (Table 21). In areas that had not been pruned, there was significance (p=<.0001) but no correlation (r=0.405) between September soil moisture and plant height (Table 21).

But when analyzing those 8 soybean rows closest to the tree lines in each transect (4 on each side), moderate significance (p=0.18), but no correlation (r= 0.176) was found between September soil moisture and soybean plant height in areas that had received the root pruning treatment (Table 21). In areas that had not received pruning treatments, there was no significance (p=0.298) or correlation (r= 0.146) between plant height and September soil moisture (Table 21).

During the analysis of the production of the plants, it was found that there was significant (p=<.0001) but no correlation (r=0.349) between September soil moisture and total mass of the soybean plants in areas that had been root pruned (Table 22). In areas that had not received the pruning treatments, there was significant (p=0.0002) but no correlation (r=0.342) between soil moisture and total mass of the plants (Table 22).

Among the soybean rows closest to the tree strips, there was significance (p=0.033) but no correlation (r=0.276) between September soil moisture and total mass in areas that received the root pruning (Table 22). This was also true in areas that had not received pruning; there was significance (p=0.0009) but no correlation (r=0.446) between soil moisture and total mass (Table 22).

Furthermore, it was found that there was significance (p=0.0016) but no correlation (r=0.281) between September soil moisture and stem mass of the soybean plants in areas that had been root pruned (Table 22). In areas that had not received the pruning treatments, there was significance (p=<.0001) but no correlation (r=0.357) between soil moisture and stem mass of the plants (Table 22).

In the soybean rows closest to the tree strips, there was significance (p=0.04) but no correlation (r=0.262) between September soil moisture and stem mass in areas that received the root pruning (Table 22). This was not case in areas that had not received pruning; there was significance (p=0.0008) but no correlation (r=0.452) between soil moisture and stem mass (Table 22).

Also, it was found that there was significance (p=0.0001) but no correlation (r=0.34) between September soil moisture and bean mass of the soybean plants in areas that had been root pruned (Table 22). In areas that had not received the pruning treatments, there was significance (p=0.0007) but no correlation (r=0.308) between soil moisture and bean mass of the plants (Table 22).

Among the soybean rows closest to the tree strips, there was significant (p=0.035) but no correlation (r=0.273) between September soil moisture and bean mass in areas that received the root pruning (Table 22). The same was true in areas that had not received pruning; there was significance (p=0.0018) but no correlation (r=0.42) between soil moisture and bean mass (Table 22).

FRACTIONAL INTERCEPTION OF LIGHT (FIL)

Fractional light interception means for both root treatments were comparable in the month of July. Fractional light interception was minutely greater in transects that had not received the root pruning treatment. The same was true in rows closest to the tree strips that had not received root pruning. The variation in FIL means across transects ranged from 5.60% to 6.02%, and 5.85% to 5.87% in rows closest to the tree line (Table 23).

There was little correlation between soybean plant height and FIL for the month of July. In areas that received root pruning treatments, there was no significance (p=0.97) or correlation (r=0.003) between July FIL and plant height (Table 24). In areas that had not been pruned, there was significance (p=0.034), but no correlation (r=0.198) between July FIL and plant height (Table 24).

When analyzing the 8 soybean rows closest to the tree lines in each transect (4 on each side), no significance (p=0.967) or correlation (r=0.005) was found between July FIL and plant height in areas that had received the root pruning treatment (Table 24). In areas that had not received pruning treatments, there was moderate significance (p=0.118) but no correlation (r=0.214) between plant height and July FIL (Table 24).

In August, fractional interception of light means for both root pruning treatments were comparable. FIL was somewhat greater in transects that had received the root pruning treatment. The same was true in soybean rows closest to the tree strips that had received root pruning. The variation in FIL means across transects ranged from 63.38% to 67.87%, and 60.79% to 67.24% in rows closest to the tree line (Table 23).

For the month of August, there was weak correlation between soybean plant height and FIL. In areas that received root pruning treatments, there was significance (p=0.0002) but no correlation (r=0.334) between August FIL and plant height (Table 24). In areas that had not been pruned, there was significance (p=0.0015) but no correlation (r=0.289) between August FIL and plant height (Table 24).

When analyzing the 8 soybean rows closest to the tree line in each transect (4 on each side), there was significance (p=0.0083) but no correlation (r=0.34) found between August FIL and plant height in areas that had received the root pruning treatment (Table 24). In areas that had not received pruning treatments, there was significance (p=0.0006) but no correlation (r=0.457) between plant height and August FIL (Table 24).

Fractional interception of light means for both root treatments were also similar in the month of September. FIL was marginally greater in transects that had received the root pruning treatment. The same was true in rows closest to the tree strips that had received root pruning. The variation in FIL means across transects ranged from 65.09% to 70.43%, and 60.61% to 66.02% in rows closest to the tree line (Table 23).

In September, there was strong correlation between soybean plant height and FIL. In areas that received root pruning treatments, there was significant (p=<.0001) and moderate correlation (r=0.673) between September FIL and plant height (Table 24). In areas that had not been pruned, there was significant (p=<.0001) and moderate correlation (r=0.65) between September FIL and plant height (Table 24).

When analyzing the 8 soybean rows closest to the tree lines in each transect (4 on each side), significance (p=.0004) but no correlation (r=0.44) was found between September FIL and plant height in areas that had been root pruned (Table 24). In areas that had not received pruning treatments, there was significance (p=<.0001) and weak correlation (r=0.566) between plant height and September FIL (Table 24).

During the analysis of the production of the soybean plants, it was found that there was significance (p=0.0002) but no correlation (r=0.33) between September FIL and total mass of the soybean plants in areas that had been root pruned (Table 25). In areas that had not received the pruning treatments, there was significance (p=0.0006) but no correlation (r=0.312) between FIL and total mass of the plants (Table 25).

Among the soybean rows closest to the tree strips, there was significance (p=0.022), but no correlation (r=0.297) between September FIL and total mass in areas that received the root pruning (Table 25). Similar findings were made in areas that had not received pruning; there was moderate significance (p=0.148), but no correlation (r=0.201) between FIL and total mass (Table 25).

Furthermore, it was found that there was significance (p=0.0007) but no correlation (r=0.299) between September FIL and stem mass of the soybean plants in areas that had been pruned (Table 25). In areas that had not received the pruning treatments, there was significant (p=0.0015), but no correlation (r=0.29) between FIL and stem mass of the plants (Table 25).

In the rows closest to the tree strips, there was significance (p=0.022) but no correlation (r=0.296) between September FIL and stem mass in areas that received the root pruning (Table 25). This was also the case in areas that had not received pruning; there was moderate significance (p=0.227), but no correlation (r=0.201) between FIL and stem mass (Table 25).

Also, it was found that there was significance (p=0.0005), but no correlation (r=0.309) between September FIL and bean mass of the soybean plants in areas that had been root pruned (Table 25). In areas that had not received the pruning treatments, there was significance (p=0.0012), but no correlation (r=0.296) between FIL and bean mass of the plants (Table 22).

Among the soybean rows closest to the tree strips, there was significance (p=0.025), but no correlation (r=0.29) between September FIL and bean mass in areas that received the root pruning (Table 25). The same was true in areas that had not received pruning; there was moderate significance (p=0.142) but no correlation (r=0.20) between FIL and bean mass (Table 25).

CHLOROPHYLL CONTENT

In August, mean chlorophyll contents between root treatments were similar. Chlorophyll content was slightly greater in transects that had not received the root pruning treatment. The opposite was true in soybean rows closest to the tree strips; areas that had not undergone the root pruning treatments had lower chlorophyll content. Variation in chlorophyll content across transects ranged from 41.88 to 42.20, and 41.77 to 42.65 in rows closest to the tree strips (Table 23).

There was only very weak to no correlation between soybean plant height and chlorophyll content for the month of August. In areas that received root pruning treatments, there was significance (p=0.0047), but no correlation (r=0.253) between August chlorophyll content and plant height (Table 23). In areas that had not been pruned, there was moderate significance (p=0.363), but no correlation (r=0.084) between August chlorophyll content and plant height (Table 24).

When analyzing the 8 soybean rows closest to the tree lines in each transect (4 on each side), no significance (p=0.55) or correlation (r=0.079) was found between August chlorophyll content and plant height in areas that had received the root pruning treatment (Table 24). In areas that had not received pruning treatments, there was no significance (p=0.93) or correlation (r=-0.012) between plant height and August chlorophyll content (Table 24).

Mean chlorophyll content between root treatments was comparable in the month of September. Chlorophyll content was slightly greater in transects that had received the root pruning treatment, but only marginally. The same was found to be true in rows closest to the tree strips that had received the root pruning treatments. Variation in chlorophyll content across transects ranged from 45.85 to 45.91, and 45.27 to 46.01 in rows closest to the tree strips (Table 23).

In the month of September, there was no correlation between soybean plant height and chlorophyll content. In areas that received root pruning treatments, there was no significance (p=0.216) or correlation (r= -0.112) between September chlorophyll content and plant height (Table 24). In areas that had not been pruned, there was also no significance (p=0.768) or correlation (r= -0.027) between September chlorophyll content and plant height (Table 24).

When analyzing the 8 soybean rows closest to the tree lines in each transect (4 on each side), no significance (p=0.768) or correlation (r=-0.039) was found between September chlorophyll content and plant height in areas that had received the root pruning treatment (Table 24). In areas that had not received pruning treatments, there was no significance (p=0.921) or correlation (r= -0.013) between plant height and September chlorophyll content (Table 24).

During the analysis of the production of the plants, there was no significance (p=0.941) or correlation (r=-0.006) between September chlorophyll content and total mass of the soybean plants in areas that had been root pruned (Table 25). In areas that had not received the pruning treatments, there was also no significance (p=0.575) or correlation (r=0.052) between chlorophyll content and total mass of the plants (Table 25).

Among the soybean rows closest to the tree strips, there was no significance (p=0.628) or correlation (r=-0.064) between September chlorophyll content and total mass in areas that received the root pruning (Table 25). Similar findings were made in areas that had not received pruning; there was no significance (p=0.941) or correlation (r=0.01) between chlorophyll content and total mass (Table 25).

Furthermore, there was no significant (p=0.721) or correlation (r=0.032) between September chlorophyll content and stem mass of the soybean plants in areas that had been root pruned (Table 25). In areas that had not received the pruning treatments, there was no significance (p=0.503) or correlation (r=0.062) between chlorophyll content and stem mass of the plants (Table 25).

In the soybean rows closest to the tree strips, there was no significance (p=0.95) or correlation (r=-0.006) between September chlorophyll content and stem mass in areas that received the root pruning (Table 25). This was also the case in areas that had not received pruning; there was no significance (p=0.86) or correlation (r=0.024) between chlorophyll content and stem mass (Table 25).

Also, there was no significance (p=0.81) or correlation (r= -0.021) between September chlorophyll content and bean mass of the soybean plants in areas that had been root pruned (Table 25). In areas that had not received the pruning treatments, there was no significance (p=0.638) or correlation (r=0.043) between chlorophyll content and bean mass of the plants (Table 25).

Among the soybean rows closest to the tree strips, there was no significance (p=0.556) or correlation (r= -0.078) between September chlorophyll content and bean mass in areas that received the root pruning (Table 25). The similar results were found in areas that had not received pruning; there was no significance (p=0.976) or correlation (r=0.004) between chlorophyll content and bean mass (Table 25).

SHADE EFFECTS ON SOYBEANS AND ENVIRONMENT UNDER TREE ROOT PRUNING CONDITIONS

The following description of results is for soybeans and environmental conditions under soybeans in crop rows nearest to strips of pines. Results are reported for areas with and without tree root pruning to effect below ground competition for resources between the soybeans and the trees, and for areas with minimal tree shading of the soybeans (rows 1-4) and maximal shading of the soybeans (rows 13-16) (Figure 4). In the previous analyses, results for samples taken from all rows (1-16) were pooled for an average mean, as were the results taken from the rows closest to the trees (1-4 & 13-16). In these analyses, results from rows 1-4 and 13-16 will be examined separately.

SOYBEAN HEIGHT

In July, soybean heights across the four replications were highly variable, but the means for both root pruning treatments under maximal or minimal shade were almost the same with almost no difference in standard deviation. The difference between means in both maximal and minimal shading never exceeded 0.25 cm. The difference between means by root pruning treatments in maximally shaded areas was 2.02 cm vs. 2.24 cm, while under minimally shaded conditions the difference between means by root pruning treatments was 2.01 cm vs. 2.08 cm (Table 26).

In August, soybean plant heights were greater in areas that received minimal shading. The means and standard deviation for both root pruning treatments under maximal or minimal shade were similar. The difference between means in maximal shading regimes was 1.37 cm and for minimal shading it was only 0.13 cm. The means in maximally shaded areas were 63.17 cm for pruned areas and 64.54 cm in unpruned areas while in minimally shaded areas the means were 67.69 cm in pruned areas and 67.56 cm in unpruned areas (Table 26).

In the month of September, soybean plant heights were greater in areas that received minimal shading. The means and standard deviation for both root pruning treatments under maximal shade were slightly different. Under minimal shade, the means and standard deviation were found to be similar. The difference between means in maximal shading regimes was 1.6 cm, but for minimal shading it was only 0.36 cm. The means in maximally shaded areas were 68.81 cm for root pruned areas vs. 70.41 cm in unpruned areas while in minimally shaded areas the means were 73.15 cm in pruned areas vs. 73.51 cm in unpruned areas (Table 26). Also, the mean height was higher in areas that were not root pruned under both shade conditions.

TOTAL MASS OF SOYBEAN PLANTS

There was some variability between mean total mass between soybean plants in each root pruning treatment. While total mass means in areas that received maximal shading were similar, there was almost a 4 g difference between means in areas that received minimal shading. Total mass means in maximally shaded areas was 18.37 g per soybean plant in root pruned areas vs. 18.44 g per soybean plant where roots were left intact. In minimally shaded areas, means were 20.38 g per soybean plant in root pruned areas vs. 16.84 g per soybean plant where roots were left intact with a significance of p=.23 (Table 26).

BEAN MASS

Bean mass means for soybean plants in maximally shaded areas were similar among treatments while means in minimally shaded areas were somewhat different. The variation in mean bean mass between root pruning treatments in maximally shaded areas was 0.11 g per soybean plant, and 3.06 g per soybean plant in areas that received minimal shading with a significance of p=0.2 (Table 26).

STEM MASS

Mean stem masses were comparable between both maximal and minimal shading regimes. Stem mass was greater in areas that had received the root pruning treatment, despite the amount of shade received. The difference in mean stem mass by root pruning treatments was 5.13 g per soybean stem vs. 5.28 g per soybean stem in maximally shaded areas, and 4.45 g per soybean stem vs. 4.96 g per soybean stem in minimally shaded areas by root pruning treatments (Table 26).

SOIL MOISTURE

Soil moisture means across all treatments and shading regimes never varied more than 4% in the month of July. Soil moisture was slightly greater in the areas that received minimal shading. Differences in soil moisture means by root pruning treatments were 12.07% vs. 12.46% in maximally shaded areas, and 13.48% vs. 15.41% in minimally shaded areas with a significance of p=.12 (Table 26).

In the month of August, soil moisture means across all treatments and shading regimes never varied more than 1%. Soil moisture was slightly greater in the areas that received minimal shading. Differences in soil moisture means by root pruning treatments were 8.18% vs. 8.43% in maximally shaded areas, and 9.04% vs. 9.16% in minimally shaded areas (Table 26).

In September, soil moisture means across all treatments and shading regimes never varied more than 1%. Again, soil moisture was slightly greater in the areas that received minimal shading. Differences in soil moisture means by root pruning treatments were 11.72% vs. 12.12% in maximally shaded areas, and 11.99% vs. 152.20% in minimally shaded areas (Table 26).

SOIL TEMPERATURE

In July, soil temperature means were similar by treatment and shading. The difference in soil temperature between maximal and minimal shading regimes never exceeded 0.36ºC. Soil temperatures were not found to be significantly lower in any treatment or shading regime. The differences in soil temperature means by root pruning treatments in maximally shaded areas were 32.22°C vs. 32.48°C, and 31.94°C vs. 32.12°C in minimally shaded areas (Table 26).

For the month of August, there was almost no difference between soil temperature means under maximal or minimal shading conditions. The difference in soil temperature between shading regimes never exceeded 0.22ºC. Soil temperatures were found to be minutely lower in root pruned areas, both maximally and minimally shaded. The differences in soil temperature means by root pruning treatments in maximally shaded areas were 29.14°C vs. 29.15°C, and 28.92°C vs. 29.15°C in minimally shaded areas (Table 26).

In September, there was only a slight difference between soil temperature means in maximally or minimally shaded areas; this difference never exceeded 0.17ºC. Soil temperatures were found to be minutely lower in maximally shaded areas. The differences in soil temperature means by root pruning treatments in maximally shaded areas were 23.22°C vs. 23.27°C, and 23.39°C vs. 23.40°C in minimally shaded areas (Table 26).

SOYBEAN FRACTIONAL LIGHT INTERCEPTION

Fractional light interception means for both shading regimes were comparable in the month of July. Fractional light interception was minutely greater in areas that received maximal shading than in areas that received minimal shading. The differences in FIL means by root pruning treatments in areas of maximal shading were 6.16% vs. 6.54%, and 5.22% vs. 5.55% in minimally shaded areas (Table 26).

In August, fractional light interception means were somewhat different between shading regimes. The difference between fractional light interception means was greatest between root pruning treatments, however, rather than between shading regimes. The differences in FIL means in zones of maximal shading ranged from 67.07% in pruned areas vs. 58.17% in unpruned areas with a significance of p=.03, and 67.62% in pruned areas vs. 64.09% in unpruned areas in minimally shaded zones (Table 26).

For September, fractional light interception means were somewhat different between shading regimes by pruning treatment. The fractional light interception means were greatest in areas that received minimal shading. The differences in FIL means in zones of maximal shading ranged from 61.01% in pruned areas vs. 53.58% in unpruned areas with a significance of p=0.25, and 71.58% in pruned areas vs. 67.21% in unpruned areas in minimally shaded zones (Table 26).

SOYBEAN CHLOROPHYLL CONTENT

In August, mean chlorophyll content between root pruning treatments and shading regimes was similar. The difference in chlorophyll content between maximal and minimal shading regimes never exceeded 1 and, in standard deviation, it never exceeded 0.1. Differences in chlorophyll content means by root pruning treatments in maximally shaded areas were 41.91 vs. 42.93, and 41.63 vs. 42.34 in areas of minimal shading (Table 26).

For the month of September, mean chlorophyll content between treatments and shading regimes was also similar. The difference in chlorophyll content between maximal and minimal shading regimes never exceeded 2. Differences in chlorophyll content means by root pruning treatments in maximally shaded areas were 45.18 vs. 45.47, and 45.01 vs. 46.78 in areas of minimal shading with a significance of $p=.16$ (Table 26).

DISCUSSION

When performing analyses on data collected, the mean tree height for each block was measured and considered a covariate (Table 1). However, while the trees were the source of shade and root effects that were evaluated in this study, and despite the fact that the tree height differed between blocks, those differences were not sufficient to be a source of significant variation in this study.

During the soybean growing season, mean monthly temperature and long term temperature were very similar (Figure 2). The soil temperature data followed the air temperature with July having the highest temperatures both above and below ground and September having the lowest temperatures. The effect of soil temperature of soybean growth and development may have been muted by the fact that measurements were taken below the immediate surface of the soil. This effect may have been buffered by the overlying soil and the true effect of soil temperature not fully realized.

Soil moisture was a variable of extreme interest in this study due to the fact that there was an expectation that this would be a major source of competition between the soybean plants and trees. Precipitation was extremely low during the months of May, June, and July, creating drought-like conditions at the study site (Figure 1). Then in August, there were large amounts of precipitation, greatly exceeding the long term averages. However, soil moisture was at its lowest amount during the month of August, as compared to July and September (Table 20). This was due to the fact that during August, the soybean plants were beginning to form bean pods and their need for water was at its greatest (Figure 7). Soybean plants that are suffering from water stress during early pod formation produce significantly less pods and seeds at harvest (Sionit and Kramer, 1977). Therefore the increased precipitation in August was a critical factor in bean pod development and yield.

Overall ANOVA analysis demonstrated that variation was significant primarily by block, shade, and the interaction of shading and blocking (Table 2-18). While this study focused the effects of shading and root pruning treatments, root pruning was only found to be significant examining bean pod mass and fractional interception of light for the month of August (Table 6, 15). This suggests that root pruning was not a significant factor effecting the growth and development of the soybeans. This is further reinforced by the blocking was a significant source of variation in 72% of all measurements taken, along with shade having significance in 44% of all measurements and shade by block having significance in 50% of the measurements while pruning was only a significant factor in 11% of all measurements.

Variation by block was a significant factor in soil moisture, soil temperature, fractional interception of light, soybean plant height, and soybean mass (Table 2-16). The consistency of this factor in the majority of measurements points to the variability of the soil gradient on the study site. With anywhere from 4 to 9 soil series present on the study site, the variation between blocks in regards to environmental and crop growth factors was expected. The presence of this source of variation in so many of the variables indicates just how significant the block effect was on this study.

Shading and shading by block were also important factors affecting the agroforestry site. These two sources of variation were found to be significant in nearly every variable measured with the exception of chlorophyll content. Shade was found to be significant in all measurements of soil temperature, and fractional interception of light. However, shade was only a significant source of variation for soil moisture in July and August, suggesting that soybean plants required less water during this period and the effect of shade on soil moisture diminished due lower water need (Table 10). Shade by block was a powerful factor affecting soybean plant height and biomass measurements, along with soil temperature and fractional interception of light (Table 2-6, 11-16). The consistent presence of this source of variation in both crop and environmental data indicates the significant effect that blocking and shading had on this study. The purpose of this study was to examine the effect of shade and root pruning of the growth and development of soybeans, and while blocking had a powerful effect on the soybeans, shade was the compelling factor in this study.

The findings of this study indicate that after five years, tree shade from, and performing tree root pruning treatments on, loblolly pines in an alley cropping system in eastern North Carolina had a modestly significant effect on the soybean crop grown in conjunction with the trees. Only slight beneficial significant differences were found between the two root pruning treatments (with and without pruning) when shading was not considered, but when shade effects were accounted for there were more positive potential impacts of root pruning (Table 26). It appears that shade on the shade-intolerant soybeans was a larger constraint on soybean growth and development than were the effects on below ground competition for moisture from adjacent trees. These findings were only moderately significant ($P \leq 0.25$), but suggestive of competition impacts in this alley cropping trial, and are biologically and ecologically logical.

While definitive conclusions about the soybean-tree interactions require higher and more consistent levels of statistical difference, the results here begin to illustrate these interactions in a long-term developing system that will emerge over several decades. The consideration of significance (p) values greater than 0.05 and 0.10 is consistent with the recommendations of Quinn and Keough (2002) who propose that levels of statistical significance be evaluated in relation to real-world environmental conditions. Further study is warranted as the trees used in this study are only 5 years old and average 3 m in height, soybean growth was modest in the study year, and the interactions between the crop and the trees will change, likely increase, over time and further demonstrate the developing competitive interactions in the mixed-cropping system.

HEIGHT AND MASS OF SOYBEANS

Results from ANOVA analysis of sources of variation demonstrated that blocking, shade, and their interaction with each other was the greatest source of variation in regards to soybean plant height and biomass. This suggests that the variation between blocks demonstrates the effect of the soil gradient on the growth and development of the soybean plants. With the high variability in soil series on the research site, this makes ecologically logical sense. In regards to shade, these results indicate that shade was a significant source of variation in the study and played a pivotal role in soybean development. It is not surprising then that the interactions between these two variables were also significant.

When results from both root treatments were reviewed, there was some moderately significant difference in total soybean plant mass and bean mass between the two root pruning treatments that should be noted (Table 19). Total mass of the soybean plants in all rows was greater in root pruned areas than in the areas with intact (competitive) roots (22 g vs. 19 g; p=.15). Total bean mass in all rows was similarly greater in root pruned than non-pruned areas (16 g vs. 14 g; p=.13). This suggests that below ground competition by adjacent and intermingled tree roots for water, nutrients, and/or rooting space slightly reduced soybean productivity, when all rows regardless of shade conditions were considered. This finding corroborates data collected on the same site from another study that was analyzing total soybean yields from 24 m and 12 m soybean alley widths which found that the 24 m alleys produced significantly greater yields (p=0.0003) than the 12 m alleys (Paul Mueller, Fred Cubbage, personal communication, March, 2012, NCSU).

Furthermore, the results also suggest that soybean plants differed only slightly between root pruning treatments in rows closest to the trees when shading was not considered. This suggests that while overall there was a slight below ground effect across all rows, that when just the rows nearest the trees, having very different shade conditions were combined, the below ground effect of root pruning and barrier installation was obscured.

Past studies have demonstrated varying effects of trees on crops in alley cropping systems in temperate climates (Lin et al., 1999; Wanvestraut et al., 2004; Zinkhan and Mercer, 1997), and that crop growth and development can be affected by the pruning of the tree roots and the installation of root barriers in alley cropping systems (Gillespie et al., 2000; Wanvestraut et al., 2004 This supports the result of a slight below ground effect across all rows while other researchers have shown that shading in agroforestry systems can have effects on crop development (Gillespie et al., 2000; Reynolds et al. 2007), as modestly observed in the current study.

SOIL MOISTURE AND TEMPERATURE

The results of this study suggest that soil moisture and soil temperature had impacts on soybean plant growth and sometimes in relation to the area of the crop alley considered and the presence of root pruning and/or shade effects. ANOVA analysis of sources of variation demonstrated that blocking, shade, and their interactions were significant (Table 8, 9, 10, 11, 12, 13). Areas with and without tree root pruning had similar moisture and temperature means with little significant difference (Table 20). The same was true when examining those rows closest to the tree strips (Rows 1-4 & 13-16), without consideration of shade.

There were, however, several significant correlations of soybean height and mass, with soil temperature and moisture, under various conditions – either across all rows or only in rows closest to the trees; without consideration for shade differences (Table 21). Soybean height and mass were positively correlated with increasing soil moisture when those relationships were significant, and soybean height was negatively correlated with soil temperature when those relationships were significant. This indicates that cooler temperatures provided by the trees could promote growth of the soybeans. But when examining the rows closest to the trees, the same was found to be true, but with very weak to no significance and almost no correlation.

There are several possible explanations for these results. The current study involved loblolly pines at 5 years of age that had an average height of 3 m (10 ft) (Cubbage et al., 2012). Weather conditions since 2007 have been highly variable with growing seasons experiencing drought-like conditions some months and heavy rainfall in others. During periods of water depletion, loblolly pines will shift root growth downward with depth during the growing period (Torreano and Morris, 1996). With the roots of the soybeans being no more than 0.5 m (1.5 ft) deep due to the tillage pan, and the roots of the trees trying to shifting downward (but likely unsuccessfully due to the hard pan and developing short, stocky tap roots), they may not have come into direct competition for moisture with each other. Furthermore, while the soybeans received the majority of the fertilizer that was applied to the field, some was inadvertently applied to the tree strips. It has been shown that when loblolly pines receive fertilization, below ground biomass production is reduced as compared to non-fertilized areas (Albaugh et al., 1998). Thus in this fertilized field the below ground competition for nutrients may have been minimal. The significance of blocking in these measurements as demonstrated by Tables 8-13 suggest the effect of the high soil variability on the research site and differences in each soil series' permeability and water holding capacity. The findings of past studies demonstrate that shading can have a significant effect of crop development (Gillespie et al., 2000; Reynolds et al. 2007) and the results from Tables 8 -13 and 26 together suggest that differing degrees of shading may obscure the measureable impact of below ground competition, especially when shading is at a minimum.

FRACTIONAL INTERCEPTION OF LIGHT BY, AND CHLOROPHYLL CONTENT OF, SOYBEANS

Fractional interception of light (FIL) is the fraction of photosynthetically active radiation that passes through the canopy unabsorbed or reflected by the plant. This is also known as canopy light interception. It is important to crop yield and growth (Purcell, 1999). The lower this fraction is, the denser the canopy structure. Chlorophyll content per unit area on a leaf is an indicator of the photosynthetic capacity of a plant and this quantity is influenced by nutrient availability and environmental stress factors such as water availability, salinity, temperature, etc. (Palta, 1990). ANOVA analysis of FIL indicated that there was significant variation by block, shading, and the interaction between the two (Table 14, 15, 16). This variation suggests the high variability of the soils across the research site and their effect on soybean development. Also, the variation in shade points to the effect of tree shade on the growth of the soybeans. Differences in FIL measurements from the soybean canopy in the current study were found to be moderately significant between root pruning treatments, but not in a consistent manner when soybeans in all rows were pooled together ($p=.15$; $p=.2$) (Table 23). FIL by the soybean canopy developed faster/greater in the bean rows adjacent to the trees under conditions with root pruning ($p=.13$; $p=.3$). This suggests that below ground competition may have moderately slowed soybean canopy development in comparison to areas where tree roots had been pruned.

Chlorophyll content of the soybeans, measured as an index of greenness, and considered positively correlated with leaf nitrogen content/concentrations (Loh, Grabosky, and Bassuk, 2002), was somewhat greater in areas adjacent to the trees where tree roots had been pruned (p=.24). This suggests below ground competition effects on the soybeans by the tree roots, even without the consideration of shade impacts. However, soybean height and mass were seldom correlated in a substantive way with chlorophyll content, even when positively correlated with FIL.

SHADE EFFECTS BY ADJACENT TREES ON SOYBEANS

The effect of shade produced by the tree component on the soybean crop suggests an effect on the growth of the soybeans. There were differences found between maximally shaded and minimally shaded areas when considering root pruning effects as well. Plant height was greater in root pruned areas that received minimal shading (p=.23; p=.2) (Table 26). This suggests that heavier shade obscures come of the impact of below ground competition, at this site. Also, soil moisture under minimal shade was greater without below ground competition from adjacent tree roots (p=.12). This also suggests that heavier shade obscures the effects of below ground competition for moisture, and also suggests a mechanism for the results in Table 26 that under the condition of minimal shade, below ground competition for moisture, can reduce bean productivity.

Furthermore, soybean chlorophyll content under minimal shade conditions was greater, suggesting higher levels of leaf greenness (and suggestive of foliar N), when roots and below ground competition from adjacent tree roots were removed (p=.16) (Table 26). This suggests that heavier shade confounds the impact of below ground competition on N availability for soybeans under these experimental conditions. When examining FIL under different shading conditions, FIL under maximal shading was greater without below ground competition form adjacent tree roots (p=.03; p=.12) (Table 26). This agrees with other results that the lack of below ground competition can lead to greater soybean productivity in this experiment, as a high FIL indicates a more rapid expansion of the soybean canopy, in this case even under heavy shade. The same pattern of greater FIL without tree roots present was also seen under minimal shade, but was not even moderately significant.

SUMMARY

This study was designed to examine the effect of trees on crop productivity on an agricultural crop of soybeans. This was done by examining the productivity of soybeans in an alley cropping system, examining the effects of trees via shading on water and nutrient competition. Shade was assessed by comparing the maximally shaded and minimally shaded sides of the alley crops. Water competition was assessed by comparing two treatments: (1) soybeans next to trees rows without any treatment; and (2) soybeans next to trees, with a trench cut to prevent lateral tree roots from growing into the soybean rows.

The results of this study indicate that loblolly pine root pruning on an alley cropping system in its fifth year had a modestly significant effect on the soybean crop, but this significance was complicated due to the effect of shading, soil variability, and perhaps weather variability year to year and various farming practices such as cultivation and weed management.

Typically, young loblolly pines develop short taproots while favoring extensive lateral-root systems in sandy or loamy soils, particularly in cases where a hardpan exists

(USFS, 2012). Previous studies have shown that without root pruning in alley cropping systems, there was a noticeable negative effect on the crop component was recorded (Gillespies et al., 2000; Wanvestraut et al., 2004). The lack of a strong significant effect on the crop by adjacent trees in the current study may suggest limited lateral root development.

Lateral root development, while not measured in the current study, may have been small due to several factors, such as water stress and lack of competition for nutrients due to fertilization (Albaugh et al., 1998). In addition, rainfall for the 2011 growing season was below average, creating drought-like conditions for the first half of the growing season (Figure 1). In other studies this has caused root growth to shift downward (Torreano and Morris, 1996) rather than laterally into the crop areas. Furthermore, it has been shown that when loblolly pines are fertilized, root development is reduced (Albaugh et al., 1998), and that too may have been the case in the current study.

Another consideration may be the repeated disking of the crop alleys in preparation for planting the soybeans. This disking would have reduced the lateral presence of pine roots into the agricultural soybean alley ways, at least at the surface level. While root pruning was used in the current study to experimentally evaluate the impact of below ground competition, it may be useful operationally to better understand the impact of disking and other forms of mechanical cultivation on alley crop yields, and to examine relative benefits in this regard of till and no-till cropping systems in this context.

This study suggests that shading had a more significant impact on soybeans than below ground competition from roots, but the impacts of root pruning may have been at least partly obscured by shade effects (Table 2-18, 26). This effect will increase over time as the trees increase in height, and must be accounted for in future studies.

These conclusions are supported by modest levels of statistical significance, and must be evaluated with caution. It can be expected that as the trees continue to grow and expand their influence over above ground and below ground effects on adjacent crops that the impacts measured will become more significant.

Results indicated that while root pruning may not be strongly effecting the growth of the soybean crop at this time, interactions between the trees and crops may become more complex and stronger over time. Conclusions from the current study are limited by one season worth of data collection, and relatively small-young trees by comparison to future conditions. Furthermore, in the current study the tree-crop interaction may have been muted by an unusually hot and dry early summer, followed by heavy rainfall at the end of the growing season.

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TABLES

Table 1. Average Height, Diameter, and Survival of loblolly pines in the agroforestry trial at Goldsboro, NC. For the current study only Blocks 1-4 for loblolly pine planted areas were used. Table adapted from Cubbage et al., 2012

	Diameter (cm)		Height (m)		%Survival
Group	Mean	StDev	Mean	StDev	Mean
Control	10.9	2.18	4.36	0.99	85
Block 5 Only	11.7	2.7	5.35	1.02	98
Blocks 1-4 Only	7.4	3.2	3.17	0.95	97

Table 2. ANOVA results for soybean plant height measurements for July 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	0.11242048	0.05621024	0.33	0.7182
Pruning	1	0.01573850	0.01573850	0.09	0.7609
Pruning x Block	3	0.53937982	0.17979327	1.06	0.3668
Shading	2	0.16483671	0.08241836	0.49	0.6157
Shading x Block	6	1.11706921	0.18617820	1.10	0.3645
Pruning x Shading	2	0.16268963	0.08134482	0.48	0.6196
Pruning x Shading x Block	6	0.43108533	0.07184755	0.42	0.8626

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 3. ANOVA results for soybean plant height measurements for August 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	241.1206979	120.5603490	6.10	0.0027
Pruning	1	0.0013007	0.0013007	0.00	0.9935
Pruning x Block	3	105.6837590	35.2279197	1.78	0.1517
Shading	2	83.2939511	41.6469756	2.11	0.1243
Shading x Block	6	338.1864597	56.3644100	2.85	0.0108
Pruning x Shading	2	8.3675759	4.1837879	0.21	0.8095
Pruning x Shading x Block	6	95.3282243	15.8880374	0.80	0.5683

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 4. ANOVA results for soybean plant height measurements for September 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	153.1484653	76.5742327	3.71	0.0260
Pruning	1	0.8247091	0.8247091	0.04	0.8417
Pruning x Block	3	87.6427501	29.2142500	1.42	0.2390
Shading	2	79.7109009	39.8554504	1.93	0.1474
Shading x Block	6	353.0445111	58.8407519	2.85	0.0108
Pruning x Shading	2	6.6079934	3.3039967	0.16	0.8521
Pruning x Shading x Block	6	101.8411388	16.9735231	0.82	0.5533

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 5. ANOVA results for total soybean biomass attributes for October 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of p≤0.1.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	1290.878067	645.439034	10.61	<.0001
Pruning	1	401.110010	401.110010	6.59	0.0109
Pruning x Block	3	753.103503	251.034501	4.13	0.0072
Shading	2	1073.080705	536.540352	8.82	0.0002
Shading x Block	6	762.956769	127.159461	2.09	0.0555
Pruning x Shading	2	137.208215	68.604108	1.13	0.3256
Pruning x Shading x Block	6	156.707232	26.117872	0.43	0.8589

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 6. ANOVA results for soybean bean pod biomass attributes for October 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	943.0668586	471.5334293	13.93	<.0001
Pruning	1	257.3674647	257.3674647	7.60	0.0063
Pruning x Block	3	550.8109404	183.6036468	5.43	0.0013
Shading	2	669.9124275	334.9562138	9.90	<.0001
Shading x Block	6	387.7844745	64.6307457	1.91	0.0804
Pruning x Shading	2	61.9633799	30.9816899	0.92	0.4019
Pruning x Shading x Block	6	89.7802010	14.9633668	0.44	0.8500

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 7. ANOVA results for soybean stem biomass attributes for October 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of p≤0.1.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	31.16984490	15.58492245	2.32	0.1004
Pruning	1	15.88066070	15.88066070	2.37	0.1253
Pruning x Block	3	20.93075127	6.97691709	1.04	0.3757
Shading	2	57.10227985	28.55113993	4.26	0.0154
Shading x Block	6	85.45807059	14.24301176	2.12	0.0518
Pruning x Shading	2	17.10886099	8.55443049	1.28	0.2814
Pruning x Shading x Block	6	22.19276192	3.69879365	0.55	0.7685

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 8. ANOVA results for soil moisture measurements for July 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	583.3542497	291.6771248	37.32	<.0001
Pruning	1	18.4620156	18.4620156	2.36	0.1257
Pruning x Block	3	151.5495469	50.5165156	6.46	0.0003
Shading	2	289.7944141	144.8972070	18.54	<.0001
Shading x Block	6	16.4429297	2.7404883	0.35	0.9091
Pruning x Shading	2	41.6222266	20.8111133	2.66	0.0719
Pruning x Shading x Block	6	45.8813672	7.6468945	0.98	0.4405

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 9. ANOVA results for soil moisture measurements for August 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	409.1567869	204.5783935	79.96	<.0001
Pruning	1	0.6760000	0.6760000	0.26	0.6077
Pruning x Block	3	14.6236250	4.8745417	1.91	0.1295
Shading	2	18.4529688	9.2264844	3.61	0.0287
Shading x Block	6	24.7629687	4.1271615	1.61	0.1443
Pruning x Shading	2	1.4368750	0.7184375	0.28	0.7554
Pruning x Shading x Block	6	16.2065625	2.7010937	1.06	0.3901

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 10. ANOVA results for soil moisture measurements for September 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	1067.419724	533.709862	51.87	<.0001
Pruning	1	3.644976	3.644976	0.35	0.5523
Pruning x Block	3	54.394132	18.131377	1.76	0.1553
Shading	2	23.112256	11.556128	1.12	0.3271
Shading x Block	6	207.319172	34.553195	3.36	0.0034
Pruning x Shading	2	0.449187	0.224593	0.02	0.9784
Pruning x Shading x Block	6	54.598177	9.099696	0.88	0.5071

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 11. ANOVA results for soil temperature measurements for July 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	645.7309661	322.8654830	356.90	<.0001
Pruning	1	0.2640625	0.2640625	0.29	0.5895
Pruning x Block	3	14.4635625	4.8211875	5.33	0.0014
Shading	2	4.1410547	2.0705273	2.29	0.1037
Shading x Block	6	11.7994141	1.9665690	2.17	0.0464
Pruning x Shading	2	1.6135547	0.8067773	0.89	0.4113
Pruning x Shading x Block	6	9.2012891	1.5335482	1.70	0.1230

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 12. ANOVA results for soil temperature measurements for August 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	13.96464594	6.98232297	13.06	<.0001
Pruning	1	0.11025000	0.11025000	0.21	0.6502
Pruning x Block	3	2.04650000	0.68216667	1.28	0.2835
Shading	2	2.82046875	1.41023438	2.64	0.0737
Shading x Block	6	7.48234375	1.24705729	2.33	0.0332
Pruning x Shading	2	0.34171875	0.17085938	0.32	0.7269
Pruning x Shading x Block	6	6.24421875	1.04070312	1.95	0.0744

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 13. ANOVA results for soil temperature measurements for September 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	188.4998882	94.2499441	106.94	<.0001
Pruning	1	0.0791540	0.0791540	0.09	0.7647
Pruning x Block	3	4.7147956	1.5715985	1.78	0.1511
Shading	2	0.4022231	0.2011115	0.23	0.7962
Shading x Block	6	9.9718972	1.6619829	1.89	0.0841
Pruning x Shading	2	1.0693335	0.5346668	0.61	0.5460
Pruning x Shading x Block	6	14.7026550	2.4504425	2.78	0.0125

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 14. ANOVA results for fractional interception of light measurements for July 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of p≤0.1.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	22.61704476	11.30852238	2.10	0.1251
Pruning	1	4.83025000	4.83025000	0.90	0.3449
Pruning x Block	3	9.20137500	3.06712500	0.57	0.6361
Shading	2	30.49605469	15.24802734	2.83	0.0612
Shading x Block	6	62.22378906	10.37063151	1.92	0.0779
Pruning x Shading	2	14.53792969	7.26896484	1.35	0.2618
Pruning x Shading x Block	6	48.26816406	8.04469401	1.49	0.1817

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 15. ANOVA results for fractional interception of light measurements for August 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	1327.858379	663.929189	3.88	0.0220
Pruning	1	1289.779490	1289.779490	7.54	0.0065
Pruning x Block	3	172.608795	57.536265	0.34	0.7990
Shading	2	651.291147	325.645573	1.90	0.1513
Shading x Block	6	2491.859677	415.309946	2.43	0.0270
Pruning x Shading	2	346.557663	173.278831	1.01	0.3646
Pruning x Shading x Block	6	1920.568915	320.094819	1.87	0.0865

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 16. ANOVA results for fractional interception of light measurements for September 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of p≤0.1.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	3427.846286	1713.923143	5.63	0.0041
Pruning	1	2007.953539	2007.953539	6.60	0.0109
Pruning x Block	3	2389.966774	796.655591	2.62	0.0518
Shading	2	8685.224220	4342.612110	14.26	<.0001
Shading x Block	6	6150.955641	1025.159273	3.37	0.0034
Pruning x Shading	2	422.064703	211.032352	0.69	0.5010
Pruning x Shading x Block	6	1635.931118	272.655186	0.90	0.4988

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 17. ANOVA results for chlorophyll content measurements for August 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of p≤0.1.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	11.1692778	5.5846389	0.46	0.6328
Pruning	1	0.0549308	0.0549308	0.00	0.9465
Pruning x Block	3	10.0470037	3.3490012	0.27	0.8434
Shading	2	14.1091460	7.0545730	0.58	0.5611
Shading x Block	6	71.1103309	11.8517218	0.97	0.4441
Pruning x Shading	2	90.2367686	45.1183843	3.70	0.0261
Pruning x Shading x Block	6	137.1181601	22.8530267	1.88	0.0857

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 18. ANOVA results for chlorophyll content measurements for September 2011 as effected by experimental treatments of adjacent shade, tree root pruning, blocking, and interactions at a significance of $p \leq 0.1$.

Source of Variation	DF	SS	Mean Square	F Value	Pr > F
Block	3	134.0965793	67.0482897	5.20	0.0062
Pruning	1	4.2162915	4.2162915	0.33	0.5681
Pruning x Block	3	89.7930879	29.9310293	2.32	0.0761
Shading	2	24.9726258	12.4863129	0.97	0.3814
Shading x Block	6	69.5596559	11.5932760	0.90	0.4966
Pruning x Shading	2	64.3147209	32.1573604	2.49	0.0849
Pruning x Shading x Block	6	121.5281076	20.2546846	1.57	0.1568

Note: Tree height by block was used as a covariate in this analysis, but was not found to be significant and was removed from the statistical analysis.

Table 19. Mean (± SD, n=4) estimates for July to September 2011 height growth, and October 2011 mean estimates of total, stem, and bean pod biomass for soybean plants by treatment following the growing season at the Cherry Research Farm, Goldsboro, NC. Treatment details are described in the text.

	Combined Soybean Samples from all Rows (1-16) --Treatment: Adjacent Tree Roots--			*Combined Soybean Samples from Only Rows Near Trees†* --Treatment: Adjacent Tree Roots--		
Attribute	Roots Pruned	Roots Not Pruned	ANOVA	Roots Pruned	Roots Not Pruned	ANOVA
Plant Height (cm)						
July	2.16 ± 0.094	2.13 ± 0.097	$F_{3, 240}$=0.03 p=0.87	2.06 ± 0.15	2.12 ± 0.15	$F_{3, 112}$ = 0.05 p=0.82
August	66.52 ± 3.89	66.98 ± 3.91	$F_{3, 240}$=0.01 p=0.94	65.23 ± 3.18	66.27 ± 3.23	$F_{3, 112}$ =0.08 p=0.77
September	72.01 ± 3.76	72.77 ± 3.76	$F_{3, 240}$=0.03 p=0.86	70.74 ± 2.92	72.11 ± 2.97	$F_{3, 112}$ = 0.14 p=0.71
Biomass (g)						
Total	22.21 ± 1.82	19.26 ± 1.83	$F_{3, 240}$ =2.06 p=0.15	19.47 ± 2.09	17.53 ± 2.12	$F_{3, 112}$ =0.68 p=0.41
Stem	5.78 ± 0.35	5.11 ± 0.46	$F_{3, 240}$ =1.08 p=0.30	5.04 ± 0.47	4.88 ± 0.48	$F_{3, 112}$ =0.07 p=0.80
Bean	16.45 ± 1.45	14.16 ± 1.45	$F_{3, 240}$=2.35 p=0.13	14.42 ± 1.68	12.61 ± 1.71	$F_{3, 112}$ =1.03 p=0.31

Note: "†" denotes soybeans in Rows No. 1-4 and 13-16 used in these analyses (Fig. 6); to assess soybean growth only in the closest proximity to the trees.

Table 20. Mean (± SD, n=4) mineral soil moisture (% volumetric moisture) at 6.4 cm depth and mean (± SD, n=4) mineral soil temperature (°C) at 7.6 cm depth along established transects by root pruning treatments for July, August, and September 2011 at the Cherry Research Farm, Goldsboro, NC. Treatment details are described in the text.

	Combined Soybean Samples from Rows 1-16 --Treatment: Adjacent Tree Roots--			***Combined Soybean Samples from Rows Near Trees†*** --Treatment: Adjacent Tree Roots--		
Attribute	Roots Pruned	Roots Not Pruned	ANOVA	Roots Pruned	Roots Not Pruned	ANOVA
Soil Moisture (%Vm)						
July	14.40 ± 1.05	13.79 ± 1.05	$F_{3, 240}$=0.63 p=0.43	13.67 ± 1.06	12.87 ± 1.06	$F_{3, 112}$=0.82 p=0.37
August	8.70 ± 0.88	8.74 ± 0.88	$F_{3, 240}$=0.00 p=0.96	8.69 ± 0.87	8.71 ± 0.87	$F_{3, 112}$=0.00 p=0.97
September	12.29 ± 1.92	12.17 ± 1.92	$F_{3, 240}$=0.07 p=0.79	12.22 ± 1.64	11.87 ± 1.64	$F_{3, 112}$=0.09 p=0.76
Soil Temperature (°C)						
July	32.23 ± 1.09	32.24 ± 1.09	$F_{3, 240}$=0.00 p=0.95	32.12 ± 1.14	32.29 ± 1.14	$F_{3, 112}$=0.44 p=0.51
August	28.99 ± 0.21	29.11 ± 0.21	$F_{3, 240}$=0.15 p=0.69	29.03 ± 0.20	29.15 ± 0.20	$F_{3, 112}$=0.18 p=0.68
September	23.33 ± 0.53	23.28 ± 0.53	$F_{3, 240}$=0.02 p=0.88	23.31 ± 0.52	23.33 ± 0.52	$F_{3, 112}$=0.07 p=0.94

Note: "†" denotes soybeans in Rows No. 1-4 and 13-16 used in these analyses (Fig. 6); to assess soybean growth only in the closest proximity to the trees.

Table 21. Pearson's correlation coefficients (r) among soil moisture, soil temperature, and height growth of *Glycine max* for July, August, and September 2011 by treatments at the Cherry Research Farm, Goldsboro, NC. Treatment details are described in text.

Monthly Correlations	**Combined - All rows**		**Rows Nearest trees**	
	Roots Pruned	**Roots Not Pruned**	**Roots Pruned**	**Roots Not Pruned**
	Soil Moisture			
July				
r†	0.16248	-0.03467	0.26481	-0.0997
P‡	0.0775	0.7154	0.0465	0.4732
n§	119	113	57	54
August				
r	0.20769	0.17463	0.08451	-0.00389
P	0.0212	0.0597	0.5245	0.9779
n	123	117	59	53
September				
r	0.38924	0.40528	0.17671	0.14693
P	<.0001	<.0001	0.1806	0.2986
n	123	116	59	52
	Soil Temperature			
July				
r	0.04654	0.04385	0.01726	0.17859
P	0.6152	0.6447	0.8986	0.1963
n	119	113	57	54
August				
r	-0.51283	-0.606	-0.36499	-0.48759
P	<.0001	<.0001	0.0045	0.0002
n	123	117	59	53
September				
r	-0.22251	-0.17337	-0.03328	-0.03679
P	0.0134	0.0616	0.8024	0.7937
n	123	117	59	53

† = correlation coefficient
‡ = probability level
§ = number of obsevations

Table 22. Pearson's correlation coefficients (r) among soil moisture, soil temperature, total mass, stem mass, and bean mass of *Glycine max* for September 2011 by treatments at the Cherry Research Farm, Goldsboro, NC. Treatment details are described in text.

Biomass Correlations	Combined - All rows		Rows Nearest trees	
	Roots Pruned	Roots Not Pruned	Roots Pruned	Roots Not Pruned
	September Soil Moisture			
Total				
r†	0.34932	0.34277	0.27697	0.44646
P‡	<.0001	0.0002	0.0337	0.0009
n§	123	116	59	52
Stem				
r	0.28111	0.35737	0.26286	0.4523
p	0.0016	<.0001	0.0443	0.0008
n	123	116	59	52
Bean Pod				
r	0.34061	0.30887	0.27395	0.42191
p	0.0001	0.0007	0.0358	0.0018
n	123	116	59	52
	September Soil Temperature			
Total				
r	-0.30641	-0.20646	-0.21254	-0.18643
p	0.0006	0.0255	0.1061	0.1814
n	123	117	59	53
Stem				
r	-0.23212	-0.15994	-0.1692	-0.09704
p	0.0098	0.085	0.2002	0.4894
n	123	117	59	53
Bean Pod				
r	-0.30451	-0.20981	-0.21888	-0.21285
p	0.0006	0.0232	0.0958	0.126
n	123	117	59	53

† = correlation coefficient
‡ = probability level
§ = number of obsevations

Table 23. Mean (± SD, n=4) fractional light interception by soybean canopy (% intercepted light) and mean (± SD, n=4) chlorophyll content (index, 1 to 100) by root pruning treatments (see Figure 6) from July, August, and September 2011 at the Cherry Research Farm, Goldsboro, NC. Treatment details are described in the text.

	Combined Soybean Samples from all rows			***Combined Soybean Samples from Rows Near Trees†***		
	--Treatment: Adjacent Tree Roots--			--Treatment: Adjacent Tree Roots--		
Attribute	Roots Pruned	Roots Not Pruned	ANOVA	Roots Pruned	Roots Not Pruned	ANOVA
<u>Fractional Interception</u>						
July	5.60 ± 0.36	6.02 ± 0.36	$F_{3, 240}$=2.07 p=0.15	5.85 ± 0.56	5.87 ± 0.56	$F_{3, 112}$=0.00 p=0.96
August	67.87 ± 2.45	63.38 ± 2.46	$F_{3, 240}$=1.67 p=0.20	67.24 ± 3.12	60.79 ± 3.14	$F_{3, 112}$=2.32 p=0.13
September	70.43 ± 4.69	65.09 ± 4.70	$F_{3, 240}$=0.79 p=0.37	66.02 ± 4.04	60.61 ± 4.07	$F_{3, 112}$=0.95 p=0.3
<u>Chlorophyll Content</u>						
August	41.88 ± 0.46	42.20 ± 0.46	$F_{3, 240}$=0.35 p=0.55	42.65 ± 0.52	41.77 ± 0.52	$F_{3, 112}$=1.41 p=0.24
September	45.91 ± 0.52	45.85 ± 0.52	$F_{3, 240}$=0.01 p=0.92	46.01 ± 0.69	45.27 ± 0.70	$F_{3, 112}$=0.57 p=0.45

Note: "†" denotes soybeans in Rows No. 1-4 and 13-16 used in these analyses (Fig. 6); to assess soybean growth only in the closest proximity to the trees.

Table 24. Pearson's correlation coefficients (r) among fractional interception of light, chlorophyll content, and height growth of *Glycine max* for July, August, and September 2011 by treatments at the Cherry Research Farm, Goldsboro, NC. Treatment details are described in text.

Monthly Correlations	**Combined - All rows**		**Rows Nearest trees**	
	Roots Pruned	**Roots Not Pruned**	**Roots Pruned**	**Roots Not Pruned**
	Fractional Interception of Light			
July				
r†	0.00349	0.19872	0.00561	0.2149
P‡	0.97	0.0349	0.967	0.1186
n§	119	113	57	54
August				
r	0.33439	0.28963	0.34066	0.45735
p	0.0002	0.0015	0.0083	0.0006
n	123	117	59	53
September				
r	0.67317	0.65223	0.44629	0.56644
p	<.0001	<0.0001	0.0004	<.0001
n	123	117	59	53
	Chlorophyll Content			
August				
r	0.25306	0.08474	0.07933	-0.01223
p	0.0047	0.3637	0.5503	0.9308
n	123	117	59	53
September				
r	-0.11223	-0.0275	-0.03923	-0.01381
p	0.2165	0.7685	0.768	0.9218
n	123	117	59	53

† = correlation coefficient
‡ = probability level
§ = number of obsevations

Table 25. Pearson's correlation coefficients (r) among fractional interception of light, chlorophyll content, total mass, stem mass, and bean mass of *Glycine max* for September 2011 by treatments at the Cherry Research Farm in Goldsboro, NC. Treatment details are described in text.

Biomass Correlations	**Combined - All rows**		**Rows Nearest trees**	
	Roots Pruned	**Roots Not Pruned**	**Roots Pruned**	**Roots Not Pruned**
	September Fractional Interception of Light			
Total				
r†	0.33092	0.31239	0.29723	0.20121
P‡	0.0002	0.0006	0.0222	0.1485
n§	123	117	59	53
Stem				
r	0.29998	0.29072	0.29641	0.16857
p	0.0007	0.0015	0.0226	0.2276
n	123	117	59	53
Bean Pod				
r	0.30931	0.29682	0.29017	0.20439
p	0.0005	0.0012	0.0258	0.1421
n	123	117	59	53
	September Chlorophyll Content			
Total				
r	-0.00672	0.05231	-0.06436	0.01025
p	0.9412	0.5754	0.6282	0.9419
n	123	117	59	53
Stem				
r	0.03251	0.06244	-0.00695	0.0242
p	0.7211	0.5037	0.9583	0.8634
n	123	117	59	53
Bean Pod				
r	-0.02159	0.04388	-0.07808	0.00422
p	0.8126	0.6386	0.5567	0.9761
n	123	117	59	53
† = correlation coefficient				
‡ = probability level				
§ = number of obsevations				

Table 26. Mean (± SD, n=4) estimates for height growth, and October 2011 mean estimates of stem, bean, and total mass for soybean plants, mineral soil moisture (% volumetric moisture), mineral soil temperature (ºC), fractional light interception by soybean canopy (% intercepted light), and chlorophyll content (index, 1 to 100) by treatment in rows no. 1-4 that received maximal shade and rows no. 13-16 that received minimal shade for July, August, and September 2011 at the Cherry Research Farm, Goldsboro, NC.

Effects of Below-Ground Root Competition Under Shade Conditions on Soybeans						
Soybean Attribute	Minimal shade			Maximal Shade		
	Roots Intact	Roots Pruned	ANOVA	Roots Intact	Roots Pruned	ANOVA
October Biomass(g)						
Total	16.84±2.93	20.38±2.88	$F_{3, 32}$=1.51 p=0.23	18.44±2.54	18.37±2.48	$F_{3, 32}$=0.00 p=0.98
Stem	4.45±0.75	4.96±0.74	$F_{3, 32}$=0.65 p=0.42	5.28±0.66	5.13±0.65	$F_{3, 32}$ =0.04 p=0.84
Bean	12.37±2.24	15.43±2.20	$F_{3, 32}$=1.70 p=0.20	13.17±2.05	13.28±2.01	$F_{3, 32}$=0.00 p=0.96
Plant Height (cm)						
July	2.01±0.24	2.08±0.24	$F_{3, 32}$=0.06 p=0.81	2.24±0.21	2.02±0.20	$F_{3, 32}$=0.56 p=0.46
August	67.56±4.70	67.69±4.62	$F_{3, 32}$=0.00 p=0.98	64.54±3.73	63.17±3.68	$F_{3, 32}$=0.09 p=0.77
September	73.51±4.50	73.15±4.45	$F_{3, 32}$=0.01 p=0.94	70.41±3.61	68.81±3.56	$F_{3, 32}$=0.12 p=0.73
Soil Moisture (%Vm)						
July	13.48 ± 1.19	15.41 ± 1.19	$F_{3, 32}$=2.57 p= 0.12	12.46 ± 1.09	12.07 ± 1.09	$F_{3, 32}$=0.11 p=0.74
August	9.04 ± 0.97	9.16 ± 0.97	$F_{3, 32}$=0.09 p=0.77	8.43 ± 0.86	8.18 ± 0.86	$F_{3, 32}$=0.09 p=0.77
September	11.99 ± 1.50	12.20 ± 1.50	$F_{3, 32}$=0.03 p=0.86	11.72 ± 1.86	12.12 ± 1.85	$F_{3, 32}$=0.08 p=0.77
Soil Temperature (ºC)						
July	32.12 ± 1.07	31.94 ± 1.07	$F_{3, 32}$=0.34 p=0.56	32.48 ± 1.27	32.22 ± 1.27	$F_{3, 32}$ =0.27 p=0.61
August	29.15 ± 0.21	28.92 ± 0.21	$F_{3, 32}$=0.63 p=0.43	29.15 ± 0.28	29.14 ± 0.28	$F_{3, 32}$ =0.00 p=0.99
September	23.40 ± 0.56	23.39 ± 0.56	$F_{3, 32}$=0.00 p=0.98	23.27 ± 0.54	23.22 ± 0.54	$F_{3, 32}$=0.01 p=0.93
Fractional Interception of Light						
July	5.22 ± 0.69	5.55 ± 0.69	$F_{3, 32}$=0.50 p=0.48	6.54 ± 0.60	6.16 ± 0.60	$F_{3, 32}$=0.35 p=0.56
August	64.09 ± 4.23	67.62 ± 4.18	$F_{3, 32}$=0.35 p=0.56	58.17 ± 4.49	67.07 ± 4.49	$F_{3, 32}$=4.90 p=0.03
September	67.21 ± 5.31	71.58 ± 5.31	$F_{3, 32}$=0.34 p=0.56	53.58 ± 6.21	61.61 ± 6.13	$F_{3, 32}$=1.35 p=0.25
Chlorophyll Content						
August	41.63 ± 0.70	42.34 ± 0.70	$F_{3, 32}$=0.51 p=0.48	41.91 ± 0.79	42.93 ± 0.79	$F_{3, 32}$ =0.83 p=0.37
September	45.01 ± 0.89	46.78 ± 0.88	$F_{3, 32}$=1.99 p=0.16	45.47 ± 1.06	45.18 ± 1.04	$F_{3, 32}$ =0.04 p=0.85

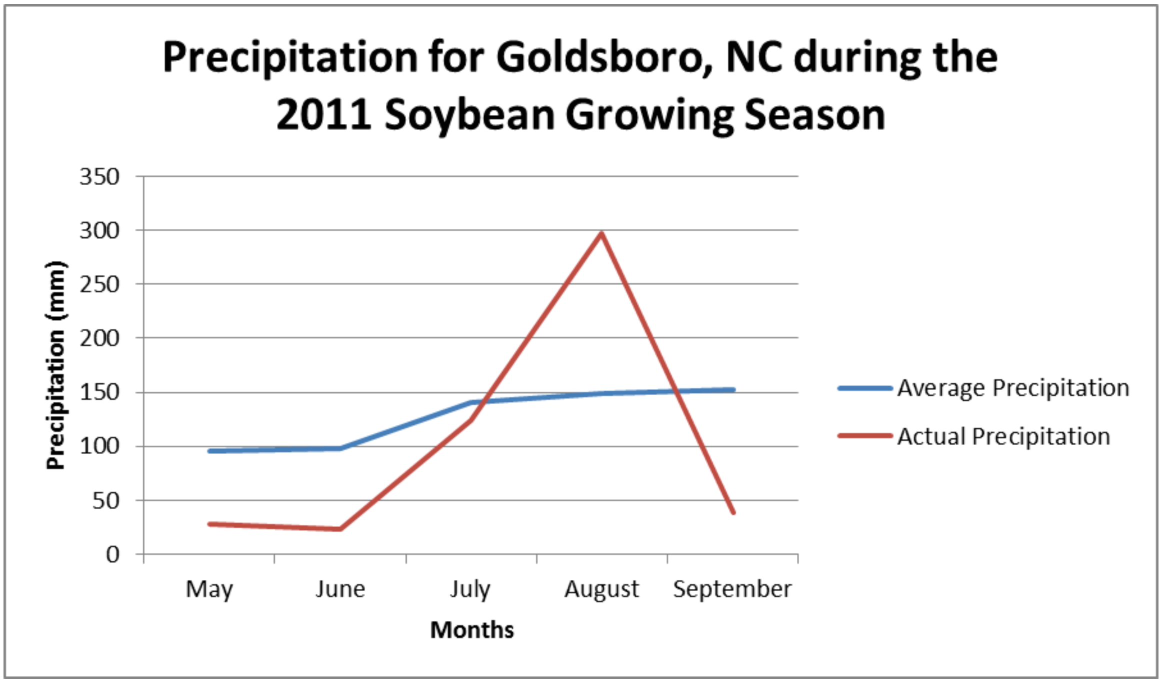


Figure 1. Average and actual precipitation for the research in Goldsboro, NC for the 2011 soybean growing season.

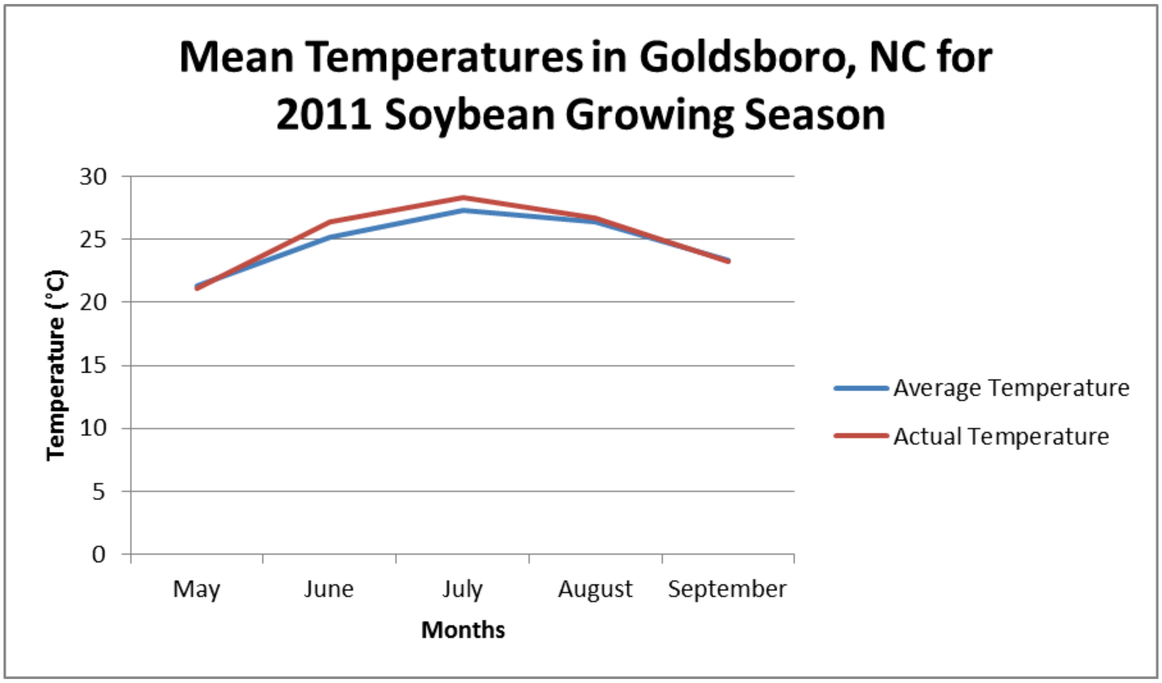
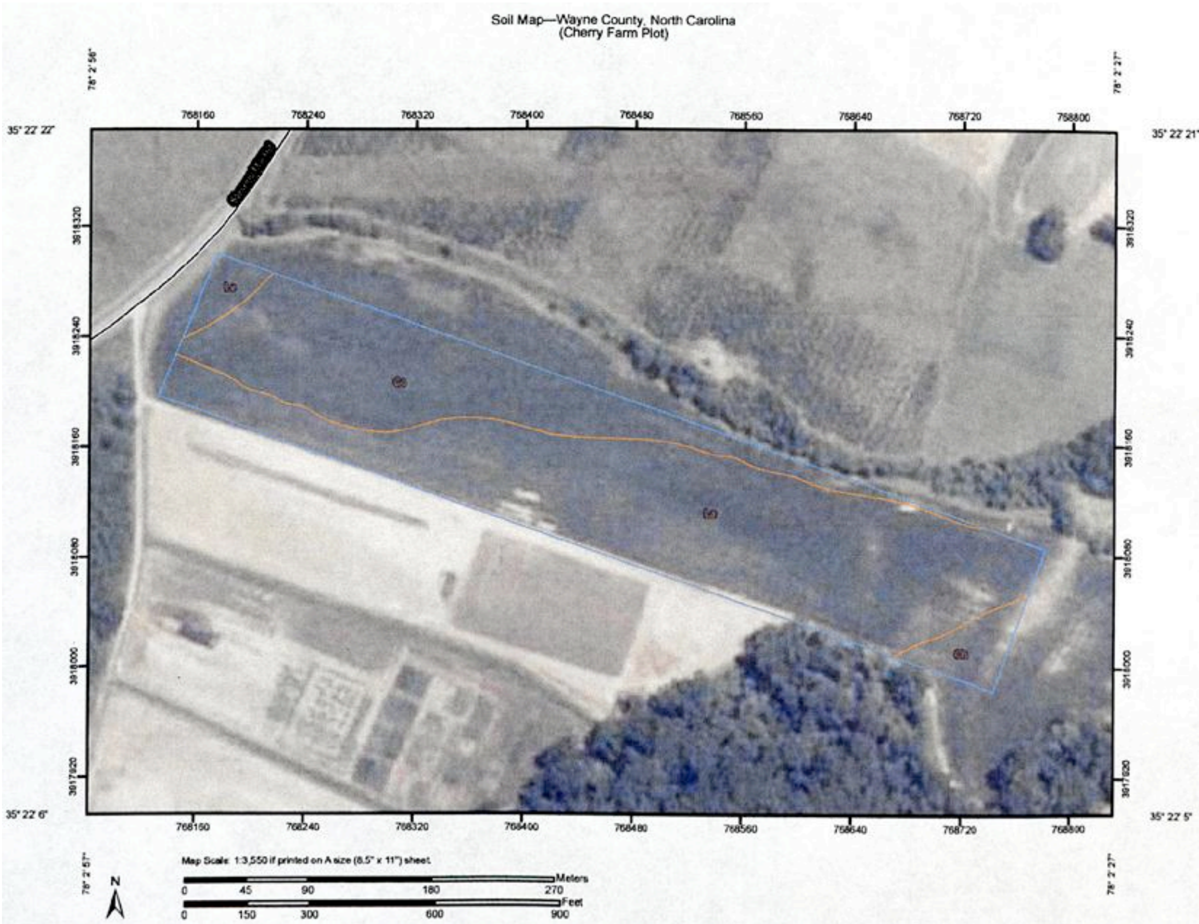


Figure 2. Average and actual mean temperatures for the research site in Goldsboro, NC during the 2011 soybean growing season.



Map Unit Legend			
Map Unit Symbol	Map Unit Name	Acres in Area of Interest	Percent of Area of Interest
Ch	Chewacla loam	0.7	4.10%
Co	Coxville loam	5.6	32.20%
La	Lakeland sand	10.7	61.40%
Le	Leaf loam	0.4	2.30%
Total for Area of Interest		17.5	100%

Figure 3. Location (35°22’14.45”N and 78°02’41.76”W). Soil map of agroforestry research site from NRCS soil survey of 1974 at Cherry Research Farm, Goldsboro, NC. Natural Resource Conservation Service image. June 16, 2006. Accessed: May 9, 2012.

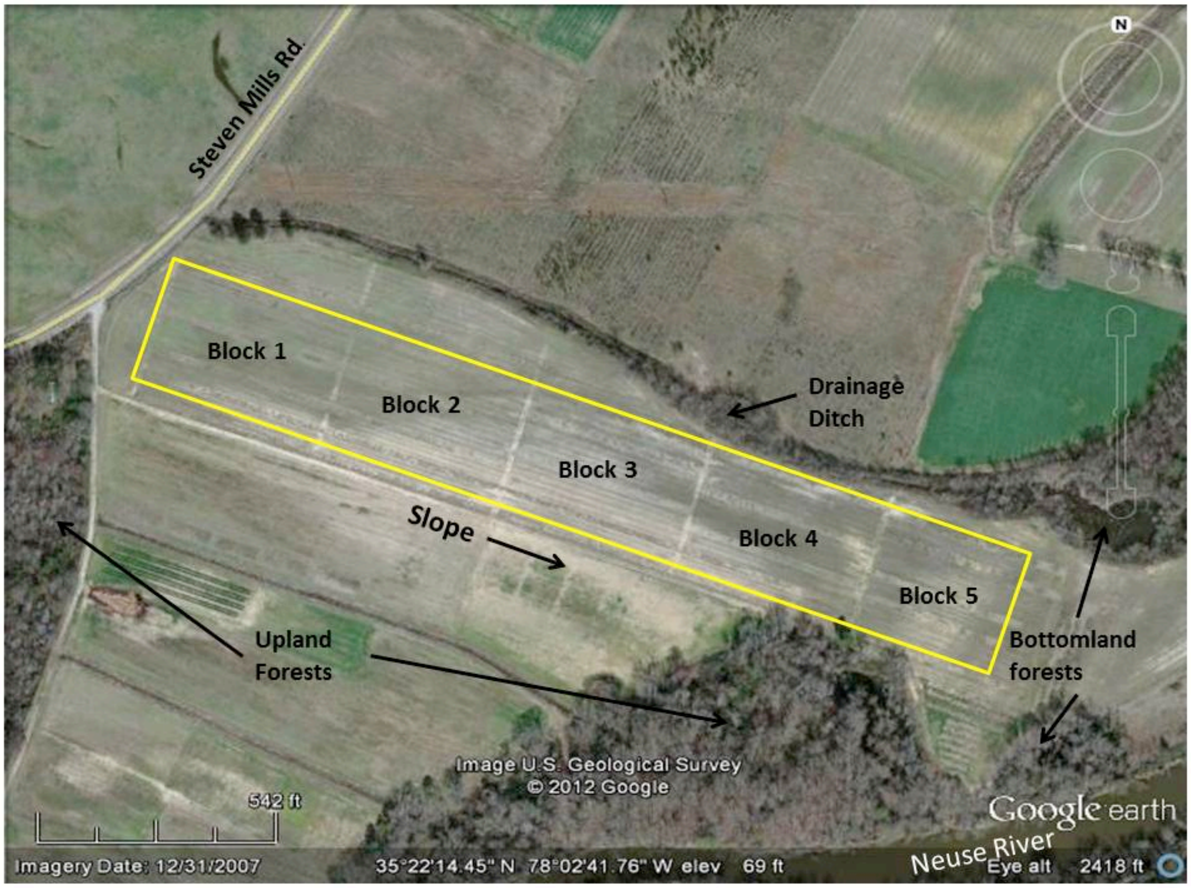


Figure 4. Location (35°22'14.45"N and 78°02'41.76"W), aerial view and arrangement of blocks (replications) of agroforestry research site at Cherry Research Farm, Goldsboro, NC. Note: faint white lines on image delineate block boundaries, as unplanted areas, as illustrated in Figure 5 (4.5 m wide tractor access/buffer). Google Earth Image. December 31, 2007. Accessed: February 20, 2011.

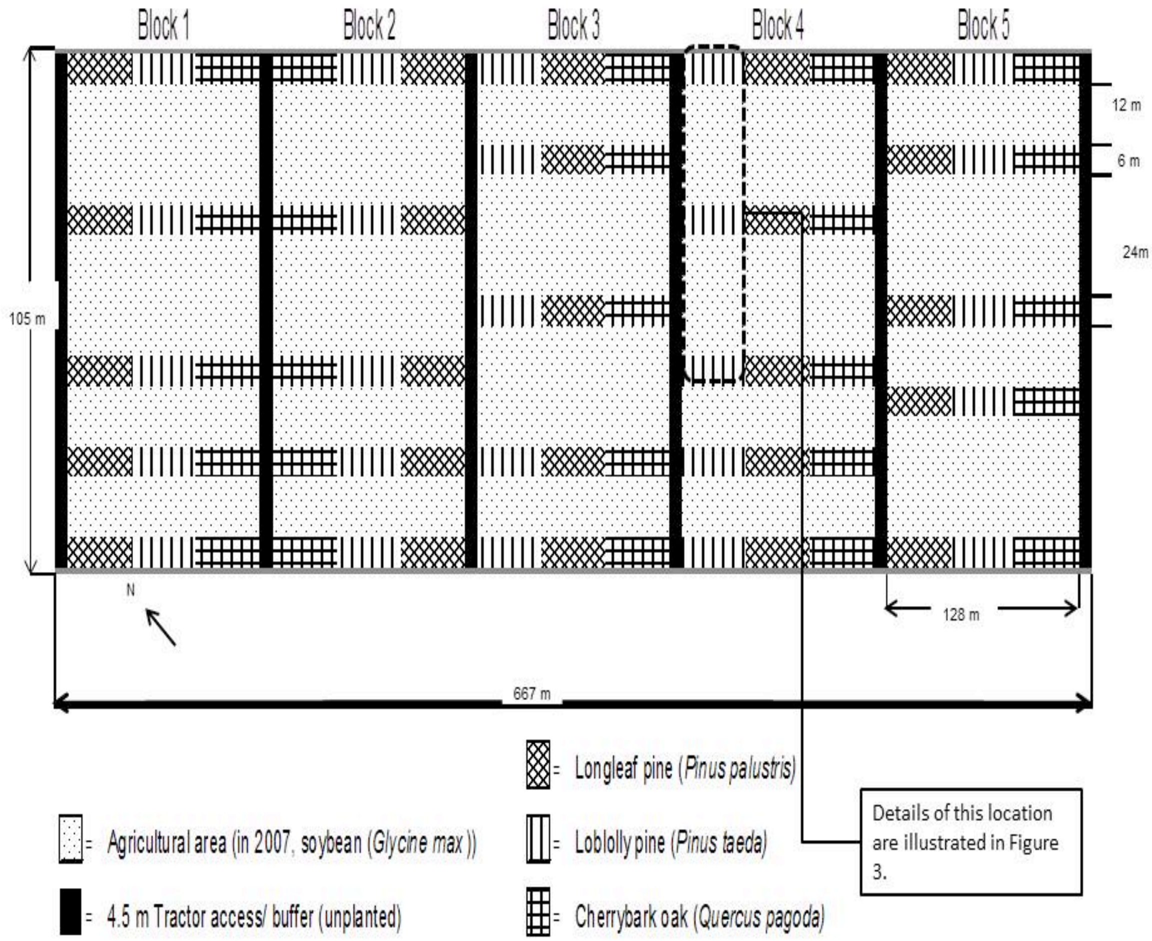


Figure 5. Layout of agroforestry study site (Goldsboro, NC) with tree strips and agricultural areas in plots of two different widths (12 m and 24 m). Figure adapted from Stevenson, 2009.

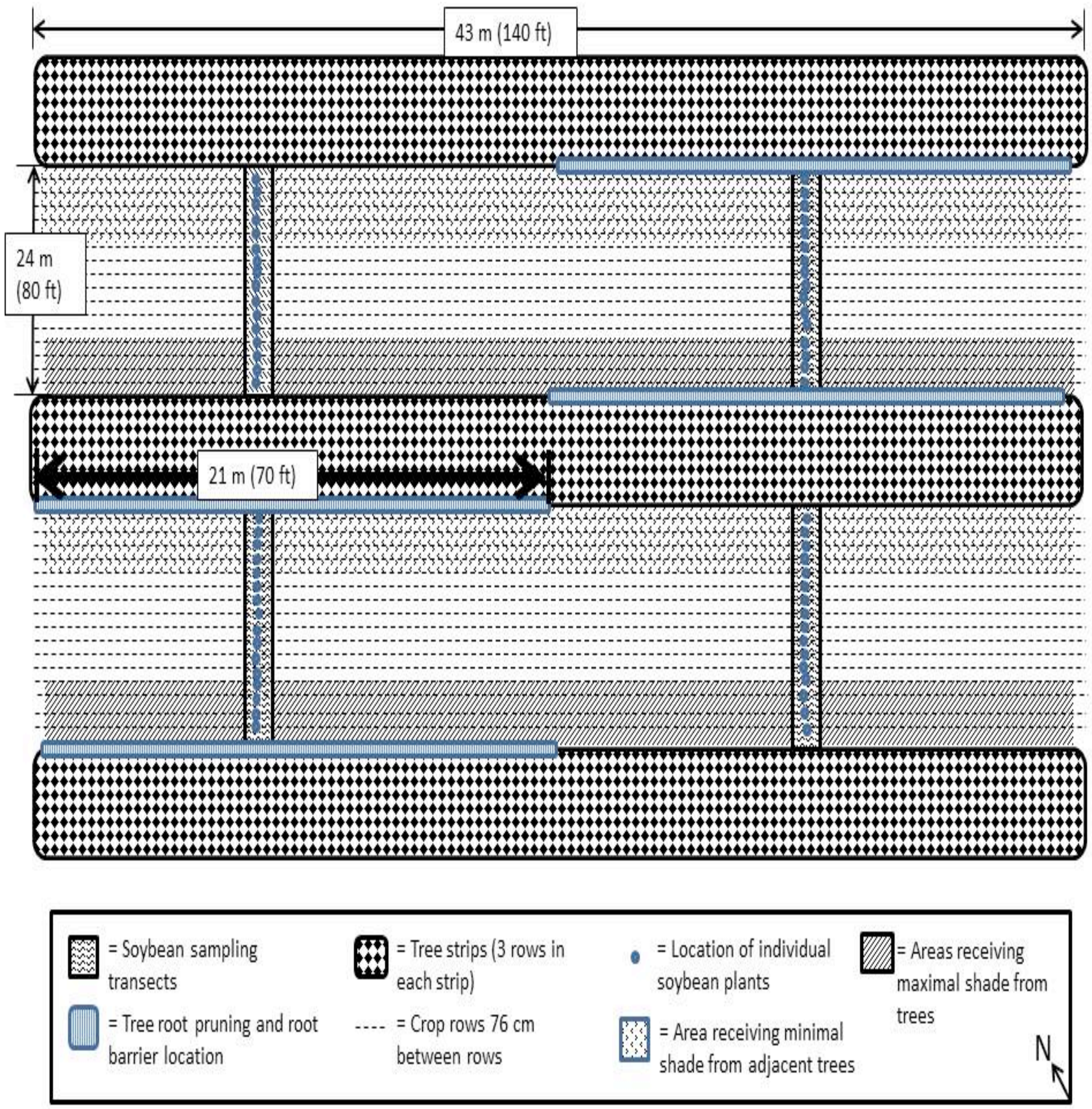


Figure 6. Detailed layout example of one replication (see Figure 5) of a soybean sampling/measurement transect having received root pruning treatments, and exposed to different amounts of shade from tree strips, on the agroforestry research site, Goldsboro, NC.

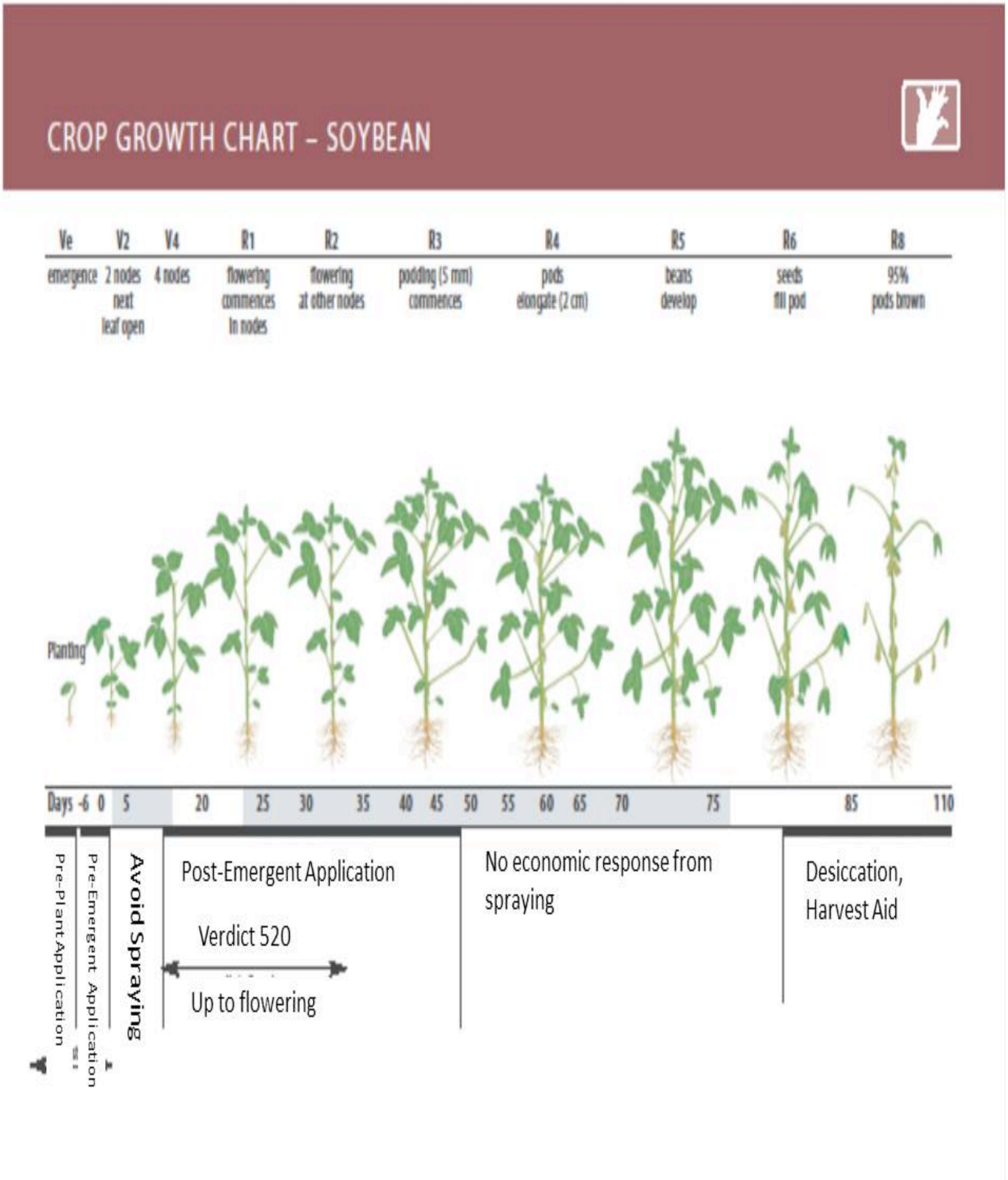


Figure 7. Soybean growth and development chart. At 75 days post-emergence in the current study, the degree of shading by tree strips on crop alleys was calculated (see Methods section for details). *Source*: Huxley, A. Fallow Solutions. March 2007. Accessed: April 16, 2012.

APPENDICES

APPENDIX A: RESEARCH SITE HISTORY 2007—2010

2007 FIELD PLANTING ACTIVITIES

On March 8 of 2007, the pre-emergent herbicide, Oust (Du Pont Co.; Wilmington, Delaware, *sulfometuron methyl*) was sprayed over the tops of the tree seedlings at 219 ml/ha (3oz/acre) using a 6.5 m (20 ft) boom off the back of a tractor so that the 3 rows of trees, each row 1.5 m apart, were completely covered with the herbicide, including a 1.75 m buffer on either side of the trees.

In the general cropping areas, Dekalb 69-71RR/YG clean till corn (Monsanto; Dekalb, Illinois) was planted with a small tire JD 6410 and a Lorenze device on 76.2 (30 in) with a narrow 6410 and a JD planter set on low range 29-27 on April 24. Also, a liquid starter (10-34-0) applied at 93.5 L/ha (10 gal/ac) with a john blue pump set on 3.25 while Lorsban in furrow was applied with a hopper set on 30 at 13.44 kg/ha (12 lb/ac). This was followed by a HI boy E809 spraying Bicep II Magnum at 3.53 L/ha (1.5 qt/ac0 in a 158.95 L/ha (17 gal/ac) solution of 30% nitrogen. On April 26 and May 2, the agricultural areas between the trees rows were disked with a JD 7810 and 630.

On May 11 of 2007, potash was broadcast applied to the entire field, including tree and agriculture areas, at 224 kg/ha (200 lb/ac) with a Chandler spreader. The field areas between the trees were again disked on May 16, and on May 18 the same areas were conditioned with a Lorenz device. Asgrow 5905 glyphosate-resistant soybeans were planted on May 21 on 76.2 cm (30 in) row spacings with a six-row JD planter set on low range 35-25, at 7 seeds /30 cm (7 seeds/ft) or 49,398 seeds/ha (123,493 seeds/ac). The soybeans were sprayed on June 15, with glyphosate at 547.6 L/ha (40 oz/ac) with a hooded sprayer. On July 26, soybeans were sprayed with glyphosate at 547.6 L/ha (40 oz/ac) and Firstrate (Dow AgroSciences; Minneapolis, Minnesota, *cloransulam-methyl*) at 21.9 ml/ha (0.3 oz/ac) with a hooded sprayer.

In August all tree blocks were weeded by hand, with special attention to remove large sicklepod that were shading seedlings, and morning glory, (*Ipomea spp.)*. Soybeans were harvested on Dec. 12, with a Case IH 2144 and yielded 670 kg/ha (10 bu/ac) for a total of 9,691 *l* (275 bu).

2008

On March 18, the tree plots were sprayed with Oust at 219 ml/ha (3 oz/ac) with a JD 6405 and a Reddick backboard sprayer (Reddick Equipment Company, Inc.; Williamston, North Carolina). Later, on April 18, glyphosate was applied at 1.2 L/ha (1 qt/ac) with a HI boy E809 on the cropping areas between the tree strips. Potash was then spread with a JD 6410 and a Chandler spreader at 224 kg/ha (200 lb/ac) on May 8. Also, Dekalb 69-71 RR/YGCB corn was planted at 29-27 low range with liquid fertilizer (10-43-00) being applied at 93.5 L/ha on the same day.

On June 12, lay-by nitrogen was applied at 261.8 L/ha (28 gal/ac) and Evik at 2.24 kg/ha (2 lb/ac) with a JD 6410 and a Sheppard lay-by sprayer. Months later, on October 6 & 7, the corn was harvested with an IH 1063 Corn Head (Case – New Holland; Racine, Wisconsin) and an IH 2144 Combine. The corn stover was mowed with a JD 7800 and a Woods Batwing (Woods Equipment Company; Oregon, Illinois) on October 22. On October

28, oats were planted across 4.8 ha (12 ac) with a JD 10' No-till and a JD 6410 at 54.72 kg/ha (48 lb/ac).

2009

Beginning of March 11, the field plot was worked with a JD 6ft Mower (John Deere; Moline, Illinois) and a New Holland 4835 (New Holland Agriculture; Racine, Wisconsin). On April 22 and 28, the area was disked with a JD 7810 towing a JD 630. The field was then sprayed with 36.86 L of (9.7 gal) CreditExtra (Nufarm Americas Inc.; Burr Ridge, Illinois; *glyphosate*) at 2.3 L/ha (1 qt/ac) with a JD 6000 #E808 sprayer.

The lower part of the field plot, closest to the river, was set aside for a Department of Transportation native grass study. This area was disked on April 22 with a JD 7810 towing a JD 630 and then sprayed with Plateau (BASF Corporation; Research Triangle Park, North Carolina; *imazameth*) at 0.87 L/ha (12 oz/ac) using a Cotton eight-row sprayer and a JD 6410.

This herbicide was also applied to the rest of the field at the same rate on May 20. On June 2, 8 ha (20 ac) were set aside for a silvopasture area which was then disked with a JD 7810 towing a JD 630. On the June 15, another 12 ha (30 ac) were planted with Ag6303 soybeans at 67.2 kg/ha (60 lb/ac) with a JD 1700 six-row planter and a JD 7800. This area was then sprayed with 52.59 L (5.625 gal) of glyphosate at 1.75 L/ha (24 oz/ac) with a JD 6000 #E808. A final application of glyphosate was applied at 2.3 L/ha (32 oz/ac) in both the silvopasture area and the crop area on July 28 with a JD 6000.

The growing season ended with the soybeans being harvested on 4 ha (10 ac) with an IH 2144 combine with an IH 1020 Grain Head (Case—New Holland; Racine, Wisconsin) yielding 3,7026 kg/ha (45 bu/ac) for a total of 12,259 kg (450 bu).

2010

In April, 15.52 ha (38.8 ac) were prepared with a JD 6410 and a new Lime Spreader at which time 21.16 metric ton (23.28 ton) of lime at 1344 kg/ha (1200 lb/ac). 8 ha (20 ac) were worked with a JD 7810 towing a JD 630 Disk. In addition, 141.82 kg (0.156 ton) of Nitrogen 30% Urea was applied at 74.8 L/ha (8 gal/ac) to 4.8 ha (12 ac). Pioneer 31G71 was applied at 28,000 kernels/ac. Another 8 ha (20 ac) were worked with a JD 6410 and a Lorenze Field Conditioner. Following the conditioning, Pioneer 33M57 was applied with a JD 7800 tractor using a JD 1700 6-row planter at 28,000 kernels/ac. Bicep II Magnum was not applied due to the trees.

During this growing season, a silvopasture study was established on 8 ha (20 ac) in late May. For this study, the research area was worked with a JD 6410 and a Shepparad 6 row lay-by. Evik-DF, a post-emergent herbicide, was applied using 2.5 bags at 1.4 kg/ha (1.25 lb/ac). Also, 887.27 kg (0.976 ton) of Nitrogen 30% Urea was applied at 280.5 L/ha (30 gal/ac) with 28.425 L (7.5 gal) of Nonionic surfactant at 4.2 L/ha (1.5 qt/ac).

In early June, another 6.8 ha were worked with a JD 6410 and a Sheppard 6-row lay-by. Evik-DF was applied at 3.4 bags at 2.24 kg/ha (2 lb/ac). In addition, 753.64 kg (0.829

ton) of Nitrogen 30% Urea was applied at 280.5 L/ha (30 gal/ac) along with 11.955 L (3.188 gal) of Nonionic surfactant at 2.1 L/ha (0.75 qt/ac).

At the beginning of September, 12.8 ha (32 ac) were harvested with a '05 Chevy 2-ton, an IH 1063 Corn Head, and an IH 2144 Combine for a yield of 8890 kg (350 bu) of field corn. Following harvest, this area was disked with a JD 7810 towing a JD 630 Disk. On 4.8 ha (12 ac), Abruzzi rye were planted at 112 kg/ha (100 lb/ac) using JD 8300 Grain Drill and a JD 6410 after the field was conditioned with a Taylor field conditioner. Another 1.6 ha (4 ac) were planted with 116 kg (8 bu) of Brooks oats at 134.5 kg/ha (2 bu/ac) using a JD 8300 Grain Drill and a New Holland 4835. Near the end of November, 160 kg (0.176 ton) of Nitrogen 30% Urea was applied with a JD 6000 at 84.15 L/ha (9 gal/ac).

APPENDIX B: FIELD PLOT HISTORY PRIOR TO 2007

The entire current study, as reported in this document, was conducted between the winter of 2010 to the late fall of 2011. It consisted of measurements only within the loblolly pine strips and soybean plots; while the overall study has been in place since 2007 and consists of three tree species and an annual change in agronomic crop species. Here is the reviewed site history from 2003 to 2007 to establish recent site uses prior to the installation of the agroforestry trial, the subject of this thesis, in 2007.

2003

Beginning on March 14 of 2003, the field plots was sprayed with 24S nitrogen at 187.054 L/ha (20 gal/ac) and Harmony Extra (Du Pont Co.; Wilmington, Delaware, *thifensulfuron methyl*) at 36.57 ml/ha (0.5 oz/ac) using two HI boy E808s (Hagie Manufacturing Co.; Clarion, Iowa) in preparation for planting of a soybean crop. On June 11 and 12 of 2003, wheat was harvested with a JD 6620 combine (John Deere, Moline, Illinois) and baled 60 round bales of straw with a wheat yield of approximately 4080 kg/ha (65 bu/ac). Following the wheat harvest, Asgrow 5603RR (Asgrow Seed Co.; St. Louis, Missouri) no-till soybeans with glyphosate resistance were planted on June 12 on 38.1 cm (15 in) row spacing with a John Deere 1560 drill (John Deere; Moline, Illinois) set on low range 35-25. On June 13, Potash (*potassium oxide,* K_2O) was broadcast applied with a chandler spreader at 112.06 kg/ha (100 lb/ac). The soybeans were then sprayed with glyphosate at 1901.64 ml/ha (26 oz/ac) with a HI boy E809 in 187.054 L/ha (20 gal/ac) of water on June 24. A subsequent application of glyphosate was made on July 10 at the back of the field due to late planting at a rate of 1901.62 ml/ha (26 oz/ac). The soybeans were then harvested on Nov. 10 with an IH 2144 (Case – New Holland; Racine, Wisconsin) at an average yield of 2284.8 kg/ha (36.4 bu/ac

2004

On April 6 and 7, superphosphate was applied to 4 different locations in field at rates of 112.06 kg/ha (100 lb/ac), 170.33 kg/ha (152 lb/ac), 291.36 kg/ha (260 lb/ac), and 243.17 kg/ha (217 lb/ac). Potash was also applied at 224 kg/ha (200 lb/ac) with a small 6410 tractor and a Lorenze conditioner (Lorenze Mfg. Co.; Watertown, South Dakota) while glyphosate was applied at 1755.36 ml/ha (24 oz/ac) as a burndown prior to corn planting. On April 7, 2004, the field was disked with a JD wide 6410 tractor (John Deere; Moline, Illinois). The following day, Pioneer 32K61 no-till corn (Du Pont Co.; Wilmington Delaware) on 76 cm (30 in) rows with an air planter set on 29-26. A liquid starter (10-34-0) was applied at 102.88 L/ha (11 gal/ac) with a john blue pump set on 4 while Lorsban insecticide (Dow Chemical Co.; Midland, Michigan) at 13.45 kg/ha (12 lb/ac) with a hopper set on 30. Bicep II Magnum herbicide (Syngenta Crop Protection, LLC; Greensboro, North Carolina, *S-metolachlor and atrazine)* was sprayed at 3.51 L/ha (0.375 gal/ac) in a solution of 30% nitrogen at 159 L/ha (17 gal/ac) after planting with a HI boy E808. On May 21, a tank mixture of 30% nitrogen at 261.88 L/ha (28 gal/ac) with Evik (Ciba-Geigy Corp.; Greensboro, North Carolina; *ametryn*) was applied as lay by to corn with a JD 6410 tractor.

Harvesting of corn silage began on July 19, but the entire field was not cut due to the corn being drier than expected.

On August 9, the area that had been cut for silage was disked with a JD 7810 tractor (John Deere; Moline, Illinois) towing a JD 630 disk harrow (John Deere; Moline, Illinois). Later on the 23rd, the remaining corn was harvested with an IH combine with a yield of 6904.7 kg/ha (110 bu/ac). After the completion of the harvest, the remainder of the field (approximately 11 acres) was disked with a JD 7810 using a JD 630 followed by the field being conditioned with a JD 7800 tractor and a Lorenze device on October 20. That same day, Tribute wheat (Luisetti Seeds Ltd; Christchurch, New Zealand) at 134.47 kg/ha (120 lb/ac) with a JD 6410 tractor and a JD 8300 grain drill (John Deere; Moline, Illinois).

2005

Beginning on March 7, 30% nitrogen at 182.38 L/ha (19.5 gal/ac) was applied overtop of the wheat with Harmony Extra (Du Pont Co.; Wilmington, Delaware; *thifensulfuron methyl)* at 36.57 ml/ha (0.5 oz/ac) using a HI boy E809 with #5 floodtips. On March 31, an application of nitrogen at 187.05 L/ha (20gal/ac) was sprayed overtop of the wheat with a JD 6405 with a backboard sprayer.

On June 15, the wheat was harvested with an IH combine at a yield of 4707 kg/ha (75 bu/ac). Two days later, Asgrow 4603RR no-till soybeans (Asgrow Seed Co.; St. Louis, Missouri) were planted at 38.1 cm (15 in) rows with a JD 1560 drill set on 31 to start and then changed to 34, but only the area from the road to the tree line due to dry, hard soil in the bottom lands. On June 28, the planting was finished using a JD 1560 drill set to 36. This was followed with a HI boy E809 and sprayed Dual Magnum (Sygenta Crop Protection, LLC; Greensboro, North Carolina; *metalochlor*) at 3.51 L/ha (1 qt/ac) with Canopy XL herbicide (Du Pont Co.; Wilmington, Delaware; *sulfentrazone & chlorimuron ethyl*) at 438 ml/ha (6 oz/ac).

On August 3, glyphosate was sprayed overtop of the soybeans with a HI boy E809 at 2194.2 ml/ha (30 oz/ac). The high rate of application was used to control the scattered areas of large sicklepod (Senna *obtusifolia*). Later on the 15th, the soybeans were sprayed for worms with a HI boy E808 using Lorsban 4-E insecticide (Dow Agrosciences LLC; Calgary, Alberta; *chlorpyrifos*) at 1.75 L/ha (1.5 pt/ac). From October 20 to November 18, soybeans were harvested us IH combine, with a poor yield of 1008.75 kg/ha (15 bu/ac).

2006

During the month of February, lime was applied to 5 sample areas at rates of 1.792 metric ton/ha (0.8 ton/ac), 1.456 metric ton/ha (0.65 ton/ac), 1.456 metric ton/ha (0.65 ton/ac), and 2.24 metric ton/ha (1 ton/ac). On March 1, glyphosate was applied to the field as a burndown with a HI boy E809 at 1901.64 ml/ha (26 oz/ac) followed by disking with a JD 7810 tractor towing a JD 630 disk harrow on March 14. The next day, the field was chiseled with a JD 7800 tractor using an eleven-tine chisel plow to help break up the hard soil. On March 30, potash was applied with a Chandler spreader and a JD wide 6410 tractor at 224.12 kg/ha (200 lb/ac). Further site preparation was done on April 5 & 6 when the field was conditioned with a Lorenze conditioner and a JD 7800 tractor, then planted with Pioneer 32K61 on 76.2 cm (30 in) rows using a six-row JD planter (John Deere; Moline, Illinois) set on low range 29-27. A starter fertilizer (10-34-0) was then applied at 93.53 L/ha (10 gal/ac) with john blue pump set on 3.25. On April 6, Bicep II Magnum was sprayed at 3.51 L/ha (1.5 qt/ac) in 168.35 L/ha (18 gal/ac) solution of 30% nitrogen.

Lay by nitrogen was then applied to the corn crop with a narrow JD 6410 with a Sheppard 8-row lay by rig (Johnnie Sheppard Equipment Co.; Pink Hill, North Carolina) at 30% nitrogen at 261.88 L/ha (28 gal/ac) with Evik at 2.24 kg/ha (2 lb/ac). The area along the ditch was disked with a JD 7810 and 630 on June 7 in preparation for a habitat experiment which was established by Lisa Forehand and David Orr called Linkers Habitat. This same area was then covered in wheat straw using a small tire 6410 tractor and a bale chopper. On June 12, this habitat plot was mowed with a flail mower to a height of 15.24 cm (6 in).

On July 14, a general crop of Syngenta NKS56—D7 soybeans (Syngenta Crop Protection LLC; Greensboro, North Carolina) were planted in a small area on no-till 38.1 cm (15 in) rows along with the establishment of another small plot. This additional plot, labeled as Emily, was disked with a JD 7810 and 630, then plowed with a JD 7800 and five-bottom plow. On July 27, plot Emily was conditioned with a small tire JD 6410 with a Lorenze, then further prepared with a rotor-tiller and bed-shaper to create 16 beds.

The small soybean crop was sprayed with glyphosate at 3.507 L/ha (1.5 qt/ac) for weed control and also sprayed for worms with Lorsban 4_E at 1.75 L/ha (1.5 pt/ac) in a separate application on August 15. From August 28 to September 13, the corn crop was harvested with an IH combine for an average yield of 7344.1 kg/ha (117 bu/ac). Linkers

Habitat was mowed with JD 4835 tractor (John Deere; Moline, Illinois) with a flail mower on September 11 and October 11. On December 7, the small plot of soybeans was harvested with a JD 6620 combine (John Deere; Moline, Illinois).