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TREE GROWTH AND TIMBER RETURNS FOR AN AGROFORESTRY TRIAL IN GOLDSBORO, NORTH CAROLINA

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Abstract: A 17 acre (6.9 ha) agroforestry research and extension alley cropping trial was established at the Center for Environmental Farming Systems in Goldsboro, North Carolina in January 2007, with a randomized block design with five replications. The demonstration planted rows of loblolly pine (*Pinus taeda)*, longleaf pine (*Pinus palustris)*, and cherrybark oak (*Quercus pagoda*), with crop lands in alleys of 40 ft or 80 ft (12.2 to 24.4 m) wide between the tree rows. Crops of soybeans (*Glycine max*) and corn (*Zea mays*) were planted in alternating years since establishment. As of 2011, survival rates were 93% for cherrybark oak, 88% for longleaf pine, and 97% for loblolly pine. Average diameter at ground level was 1.0 in (2.5 cm) for cherrybark oak, 2.1 in (5.3 cm) for longleaf, and 3.2 in (8.1 cm) for loblolly. Heights averaged 4.6 ft (1.4 m) for cherrybark oak, 5.2 ft (1.6 m) for longleaf, and 10.4 ft (3.2 m) for loblolly. Growth, yield, and economic projections for traditional timber production indicated that species volumes and values tracked the current height and diameter relationships. Loblolly pine had the largest projected internal rate of return, at 7.2%, followed by longleaf pine at 3.5%, and cherrybark oak at 2.9%. There might be more loss in crop and silvopasture production with loblolly, however, and production of pine straw for longleaf or game mast for cherrybark oak may offer other benefits. Crop yields on the sandy soils were very poor during the four years observed.

Keywords: forests, crops, growth and yield, alley cropping, economic analyses

INTRODUCTION

The use of agroforestry systems is expanding throughout the world. A broad literature about agroforestry documents its potential, which we paraphrase here, but do not cite due to space constraints. Tree and crop systems or tree and pasture systems may offer advantages to farm and forest owners in the United States by providing attractive farming returns while reducing financial risk; reducing risks from fire or other abiotic or biotic events; and helping adapt to climate change through better low-intensity management of site nutrients and shade for livestock. Silvopasture and agroforestry systems may offer many benefits such as more biological diversity and risk reduction advantages than monoculture crops, as well as potential financial diversification at a small-to-medium scale.

While silvopasture systems are applied to some extent in Florida and the Gulf Coast, they are not implemented extensively in the U.S. Agroforestry systems, such as pecans and livestock, are more developed in the U.S.

Researchers in Florida, Missouri, and Mississippi have examined silvopasture and agroforestry systems in the U.S. South. However, little research or applications have occurred in the Carolinas and Virginia, so we can learn more from the integration of the common practices in the Deep South if they are coupled with demonstration and research projects in the Carolinas.

Based on this perceived need, we began discussion of agroforestry projects in North Carolina in 2006. In January of 2007, we established a 17 acre (6.9 ha) demonstration and research alley cropping system at the Center for Environmental Farming Systems (CEFS) in Goldsboro, North Carolina. The objectives of this project were to: (1) provide a demonstration of the potential for agroforestry systems in North Carolina for landowners, farmers, natural resource professionals, and researchers; (2) establish a long-term research project that could be used to monitor the implementation of an alley cropping and eventually silvopasture system at the site; (3) measure the tradeoffs of trees on crops and eventually livestock production; and (4) provide a research site for graduate students and professors interested in agroforestry.

METHODS

This paper describes the early results from our project to establish the agroforestry trial site, focusing on tree survival and growth, models of forest growth and yield, and estimates of economic returns for three tree species planted at the site. Subsequent research will provide more complete analyses of the interaction of timber and crop returns, based on crop yield data, plant competition effects, and input costs for both trees and crops.

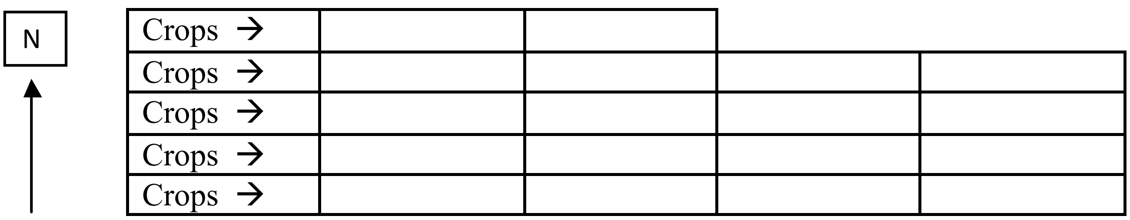
Project Establishment

The project was developed as an extension and research trial at the Center for Environmental Farming Systems (CEFS)/Cherry Farm Research site near Goldsboro, North Carolina, which is owned by the state and managed by the North Carolina Department of Agriculture and North Carolina State University. The CEFS agroforestry site is a 17 acre (6.9 ha) alluvial river bottom in a bend of the Neuse River, one of the major tributaries from the Piedmont of North Carolina to the Atlantic Ocean. The site has a mixture of soil types and drainage characteristics, ranging from sandy well drained soils at the upper, west end to deeper clays and organic soils at the lower east end closest to the Neuse River. The trees were planted in an existing field that had been planted in crops of corn or soybeans for many years. However, it tended to flood often, making it a good site for considering trees as an alternative crop.

We planted several tree species in an alley cropping system to assess their potential on the site: loblolly pine (*Pinus taeda*), longleaf pine (*Pinus palustris*), and cherrybark oak (*Quercus pagoda*). The design consisted of rows of trees with open land for crops—or eventually pasture—between them (Figure 1). The tree rows and crop alleys ran east to west, so that the sun could be on the open land as much as possible as the trees grew larger. The trees were planted in three lines per row, with a diamond spacing of 6 ft (1.83 m) between trees in each line, and 6 ft (1.83 m) between lines. The open areas for crop alleys were 40 ft (12.2 m) or 80 ft (24.4) wide.

The placement of the trees and crop rows was established in a randomized block design across the site, with 5 replications of each of the tree/crop variations extending down the field from the upper and drier end to the lower and wetter end. The three tree species also were distributed randomly across each replication, in bands of loblolly, longleaf, or cherrybark. Each band of trees in the replication was 140 ft (42.7 m) long, with 21 trees planted per row. We also established 10 ft (3.05 m) by 10 ft (3.05) check plots at the lower end of the field, adjacent to Replication 5 of the main trial. In the check plots, each of the species were planted in square blocks to compare the growth of trees in the alleys with that of trees planted in a conventional forest plantation. Roughly 1,950 trees of each species were planted in the replications; 200 in the check blocks.

Figure 1. Representation of Alley Cropping Project Layout, Goldsboro, NC
Three tree rows (6 ft by 6 ft) in each row; each species in each replication (420 ft / 128 m)
Trees established in replications (Rep) as noted at the bottom of the diagram were:
LO-Loblolly pine; LL-Longleaf pine; CB-Cherrybark oak



The site was laid out with tape measure, string, and flagging, and seedlings were planted in January 2007 according to the randomized block design by a crew of professors, graduate students, and work release prisoners at the CEFS farm. All seedlings were purchased from the North Carolina Division of Forest Resources (DFR) nursery nearby in Goldsboro. The loblolly and cherrybark oak were provided as bare root seedlings, and the longleaf were containerized stock. The cherrybark oak were graded by a DFR forester who assisted us on the site, and poor seedlings were discarded. Loblolly pine seedlings were planted by hand with a dibble bar, and cherrybark oaks were planted with Modified KBC bar with 6 inch blade to open a wide hole for broad roots. Longleaf were planted with a "pottapooki" drop tube in the sandier soil, but needed a dibble in the muddy bottomland soil. After planting, when the field dried up enough later in the season, the crop rows were ripped up to the edge of each row to provide better drainage for the trees.

After establishment, in March of 2007 and 2008, Oust (Sulfometuron methyl) pre-emergent herbicide was sprayed over the top of the planted seedlings that still had hard closed buds. The treatment was applied at 3 ounces per acre using a 20 ft boom, indicating a spraying distance of 5.7 ft on either side of the tree rows. In August 2007, the entire area of tree strips was weeded with hand hoes, especially to remove sicklepod (*senna obtusifolia*) and morning glory (*Ipomoea purpurea*), which were choking the seedlings.

Alternating crops of corn (*Zea mays*) and soybeans (*Glycine max*) have been planted each year since 2007, with soybeans in 2007, corn in 2008, soybeans in 2009, and corn in 2010. In 2008, the second year after planting, a major flood inundated much of the site for about a month. The flood may have affected tree growth, and reduced crop yields greatly. In 2010, a major drought occurred from June until August, which basically eliminated any crop yield as well. Deer browsing was almost no problem for the pines and more common for the oaks, but only seemed to nip the lead apical stem growth, not reduce overall vigor.

Timber Growth, Yield, and Financial Analyses

In January 2011, after four years of growth, we measured the survival, diameter, and height of the trees. Diameter was measured just above the root collar with calipers; height with an extension pole. These data were used to calculate survival rates and growth rates used in timber growth and yield models. At four years old, the trees are too young to be used directly in growth and yield models, but they do help inform the starting points for models that require older stands at initiation.

We then used various growth and yield models to project the growth of each species over time based on its growth in pure stands. Since there are not models for growth for tree in alley systems, we used general equations and software packages for whole stands, and then compared them. Subsequently we will multiply the results from the whole stand models by the percentage of the area in tree rows to estimate effective timber yields per acre. For this analysis, we simply compared the growth rates of different species for whole stand models based on the best available literature. We obtained the projected growth rates, input costs, projected timber yields by product class, and product prices. These production functions, input costs, and output prices were used to estimate financial returns to each tree species. We will add crop yields, costs, and prices into an integrated economic model as this demonstration progresses.

Cherrybark Oak.—The basic information for the cherrybark analysis was generated using the NATYIELD program developed by Smith and Hafley (1986). The site index used at reference age 50 was 70 ft. Two different projections were made for stands that were planted under different regimes. One projection used a stand that was planted using a typical hardwood 8 ft by 10 ft spacing and contained 540 trees per acre (TPA) initially. The average basal area per acre at age 20 was assumed to be 40 ft^2. The basic production data generated by NATYIELD were then used in another volume equation as a check to produce a second stream of volume projections under the same regime for comparison.

The analysis used an 80 year rotation with a pre-commercial thinning in year 30 and a commercial thinning in year 55, with 1/3 of the basal area in the stand was removed each time. In the commercial thinning of 868 ft^3/ac it was assumed that 2/3 of the harvested biomass would be used for pulpwood, and 1/3 would be used for sawtimber. In the final harvest of 3918 ft^3/ac, 100% of the harvested biomass was used for sawtimber. The prices used in this analysis were taken from the 4th Quarter 2010 Timber Mart-South hardwood stumpage prices for the North Carolina Coastal Plain region ($31.41 per ton for sawtimber, $4.29 per ton for pulpwood).

For a capital budgeting analysis, an interest rate of 4% was used to calculate the present value of the two commercial harvests. Costs were $300 per acre for planting, $75 per acre chemical treatment in year 1, and $5/acre/year in property taxes.

Loblolly pine.**—**The loblolly pine volume equations and financial returns were based on prior research by Siry et al. (2001), which used the TAUYIELD computer program. This assumed the planting rate was 600 TPA, with a site index of 60 ft at age 25. Thinning volumes were 475 ft^3/ac at age 17, with 75% pulpwood ($8.45/ton) and 25% chip-and-saw ($16.89/ton), also based on Timber Mart-South (2010) pine prices for eastern North Carolina. Final harvest volumes were 2225 ft^3/ac at a final harvest of age 25, with 23% chip-and-saw; 67% small sawtimber ($29.82/ton); and 10% large sawtimber ($61.92/ton). Input costs were $400 per acre for site preparation and chemical release, and $5/acre/year in property taxes.

Longleaf Pine.**—**As with the cherrybark oak analysis, the underlying longleaf pine growth in volume was derived using the NATYIELD program developed by Smith and Hafley (1986). The base scenario was specified as 500 TPA, 70 ft^2 of basal area per acre and a site index of 70 ft at year 50. For comparison, the production data (volume, average height, TPA and basal area) generated by NATYIELD were used as inputs for three other longleaf pine growth models from available literature. Each model produced very similar results, so the NATYIELD outputs were used to derive the financial calculations. The analysis presented represents a simple timber production scenario. In most cases, management of longleaf pine will be more complex including considerations for pine straw, prescribed burning, and wildlife habitat benefits. The simple timber production scenario is more appropriate for this test site, where longleaf is intercropped with other species and agricultural crops and less likely to be intensively managed for pine straw with crops or livestock, although this may be possible.

The financial scenario assumes a 40 year rotation with commercial thinning at age 25. During this thinning, basal area is reduced to 60 ft^2 and approximately 10 tons of timber are harvested per acre. The material thinned is assumed to be 75% pulpwood ($8.45/ton) and 25% chip-and-saw ($16.89/ton). Final harvest is treated as a clear cut, approximately 54 tons per acre, and consists of 20% chip-and-saw, 50% sawtimber ($29.82/ton) and 30% large sawtimber/poles ($61.92/ton). Longleaf pine prices were the same as for loblolly, from Timber Mart-South (2010). Costs included site preparation and planting at $325/acre, chemical herbaceous release at year 1 for $75/acre, and an annual property tax of $5/acre.

RESULTS

Precipitation at the Goldsboro Cherry Farm Research Site varied widely in the four years since planting. The first year of planting, 2007, was relatively dry at the site, with only 15 in of rain falling from March 1 to September 30. The second year started out with flooding, as 13.3 in of rain fell between February, March, and April. May, June, and July were dry, with 8.9 in of rain and high evapotranspiration rates. August and September returned to flooding, with 14.6 in of rain. Rainfall was distributed more evenly across the growing season in 2009, with 3.2 to 4.6 in per month. Drought returned in the Spring of 2010, with only 5.37 in falling in April, May, and June, more in July and August (8.25 in), and a flood in September (12.7 in).

The floods and droughts on a site with sandy soil on the high end and wetland soils on the low end produced acceptable crop yields in only two of the four years and virtually none in 2010. The trees, on the other hand, grew relatively well. The site averaged only 12 bushels per acre of soybeans in both 2007 and 2009; 51 bushels per acre of corn in 2008; and 20 bushels per acre in 2010. The wet end of the field in Replication 5 was better for crops, at 30 bushels per acre of beans in both years; 112 bushels per acre of corn in 2008; and 52 bushels per acre in 2010. Nevertheless, the crop yields were poor given the weather we experienced since 2007.

Tree Growth

The results from the tree survival and growth measurements at age 4 in 2011 are summarized in Table 1. The survival rates were very consistent across all replications from the upper to lower end of the field. There was better tree growth in the replications in the field at the lower, wetter eastern end by the Neuse River (Rep 5) than at the upper, drier western end (Rep 1). In fact, across all species the average height and diameter in replication 5 was statistically greater (α=0.01) than in the other replications. Thus we summarized the data for the totals of all replications 1-5; for replications 1-4; for replication 5; and for the check plots.

Table 1. Survival, Diameter at Base, and Height of Trees in Goldsboro Alley Cropping Project at 4 Years Old, by Replication and Control Plots, 2011

Characteristic[1]	Loblolly Pine	Longleaf Pine	Cherrybark Oak
Survival, All Replications (%)	97%	88%	93%
Diameter (in)			
All Replications	3.2	2.1	1.0
Replications 1-4	2.9	2.0	1.0
Replication 5[12]	4.6	2.3	1.4
Check Plots	4.3	2.0	1.7
Height (ft)			
All Replications	10.4	5.2	4.6
Replications 1-4	9.3	4.9	4.2
Replication 5[3]	15.7	6.3	6.6
Check Plots	14.3	4.7	8.0

[1]All diameters and heights between species were statistically significant (α=0.01).
[2]For longleaf pine and cherrybark oak, the mean diameter in Rep 5 is statistically different from the mean of the check plots (α=0.01). For loblolly this difference was significant at α=0.10.
[3]The mean height in Rep 5 is statistically different from the mean of the check plots for all species (α=0.01).

Survival rates were 93% for cherrybark oak, 88% for longleaf pine, and 97% for loblolly pine.

These were very consistent across the entire field. These survival rates were very good, with almost all of the trees performing well. The loblolly grew fast, as expected. The longleaf did well, usually coming out of the grass stage by the second year. The hardwoods looked the poorest among the annual weeds, especially at the dry end of the field, but were surviving.
Across all replications, average diameter at ground level was 1.0 in for cherrybark oak, 2.1 in for longleaf, and 3.2 in for loblolly. Heights averaged 4.6 ft for cherrybark oak, 5.2 ft for longleaf pine, and 10.4 ft for loblolly pine. All the differences among the diameter and height among species were significantly different (α=0.01).

Note that the results did vary by location in the drier or wetter ends of the field. Longleaf grew about the same regardless of location in the field, and performed comparatively better on the sandier sites, but still fared relatively well on the wetter, somewhat more organic replications, although all the soils were sandy or rocky alluvial mixtures. Longleaf had the shortest height growth on the very wet check plots, which were saturated with water during much of the early growing season. Loblolly and cherrybark oak grew better as the field retained more moisture, with the best growth in loblolly pine being in replication 5, and the best for cherrybark being in the very wet check plots.

Growth, Yield, and Financial Returns

Table 2 summarizes the management regimes, growth, and harvests, as well as the financial results for the three tree species, based on a pure timber production regime for each. Loblolly pine grew the fastest according to the growth and yield equations, at an average of 108 ft^3/ac/yr. Longleaf grew at an average of 71 ft^3/ac/yr, and cherrybark oak at 61 ft^3/ac/yr. These growth rates and shorter rotations favor loblolly, then longleaf, then oak.

Table 2. Growth and Capital Budgeting Results for Three Species for Timber Production Management Regime at a Discount Rate of 4%

Species	Rotation Age	Harvest Years	Total Volume Cut (ft^3/ac)	Net Present Value ($/ac)	Land Expectation Value ($/ac)	Annual Equivalent Value ($/ac)	Internal Rate of Return (%)
Cherrybark Oak	80	55&80	4,846	-360	-376	-15	1.9
Longleaf Pine	40	25&40	2,826	-49	-61	-2	3.7
Loblolly Pine	25	17&25	2,700	493	789	32	7.2

Loblolly pine had the best timber returns at a 4% discount rate, earning a Land Expectation Value (LEV) of $789 per acre, and Internal Rate of Return (IRR) of 7.2%. Longleaf pine and cherrybark oak had negative Net Present Values and LEVs at the 4% discount rate, given the initial costs of

$300 to $400 per acre. The IRRs were 3.7% for the longleaf stand and 1.9% for the cherrybark oak. Costs should be less for planting on open agricultural fields than the generic averages we used, so returns for all species could be slightly greater.

These pure timber production financial differences among species may be reduced by agroforestry factors. They may differ somewhat at the denser planting rates represented by the rows of trees—1280 trees per acre, but on only a portion of the area. The results also may vary when longleaf pine straw potential is considered, at least in the early crop years. And the cherrybark oaks will offer greater mast and wildlife advantages. Furthermore, as noted on our soils, while loblolly grew better everywhere, its advantage was much less on the drier, sandier sites, and cherrybark grew very well in the wet, frequently flooded end of the field. Furthermore, the interaction of the growing trees on the adjacent agricultural land use has yet to be determined. There will be impacts from increasing weather variations year-to-year, increasing shade, reduced wind, increased habitat for biodiversity (some good, some bad for the crops), reduced soil compaction over many years from less area being frequently trafficked, etc.

CONCLUSIONS

This agroforestry alley cropping system in North Carolina in a Neuse River bottom with sandy to wetland soils has been successful at establishing a forest stand of three species, and with high survival rates. The trees averaged survival rates of 88% for longleaf pine to 97% for loblolly pine after four years of floods and droughts. In fact, the trees prospered more than the crops, which were almost failures two of the four years on the poor sandy soils common on the site. This might suggest that a silvopasture system would be better on the poor soils than crops.

We could not yet use the tree survival rates to populate forest growth and yield models directly, but they at least indicated that plantation models are representative. They also indicated that the trees in the rows still grew like trees in the check plots. The plots had higher diameters and heights, but this seemed to be largely a function of the better, wetter sites, not the type of planting pattern. So we used conventional growth and yield models, with checks on those projections for each species. These results showed that relatively faster growth rates for loblolly pine yielded greater financial returns for pure timber production management regimes, followed by longleaf pine and then cherrybark oak. However, both longleaf and cherrybark have more potential for other products, which could reduce this financial advantage for loblolly.

In addition, the alley crop and livestock interactions will make this agroforestry trial and financial results more complex. Loblolly pine grows well and fast, but shades the crops faster, and has a wide spread and bushier crown than longleaf at least. The cherrybark oak starts slow, but may be very productive on deep red river bottom sites in the longer run, and be hardier as an alley cropping system moves from trees and crops to trees and livestock. The longleaf may be able to produce some pine straw in its rows if it is not grazed. It also may provide better habitat for wildlife species for hunting as well as for livestock. Furthermore, longleaf can grow to a much longer rotations of about 80 years, and can be used as habitat for red-cockaded woodpeckers, which may at least be environmentally important, and may offer opportunities to receive payments for those environmental services.

We will measure the crop yields and perform those financial calculations based on actual timber growth and yield as this project progresses and the trees mature. We will look forward to more demonstration, research, and education about these systems as we manage and monitor one of the first specifically planned and implemented agroforestry systems in North Carolina.

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