Early tree growth, crop yields and estimated 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. Loblolly pine (*Pinus taeda*), longleaf pine (*Pinus palustris)* and cherrybark oak (*Quercus pagoda*) were planted in staggered rows, with each species planted for 140 ft (43 m) per replication. Crop land alleys of 40 ft or 80 ft (12.2–24.4 m) wide were left 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 tree 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 pine and 10.4 ft (3.2 m) for loblolly pine. Growth, yield and economic projections for traditional timber production indicated that species volumes and values tracked the height and diameter relationships measured on the site. Loblolly pine had the largest projected internal rate of return, at 7.2%, followed by longleaf pine with pine straw harvests at 5.5%, longleaf without pine straw at 3.5% and cherrybark oak at 1.9%. 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 on the site were very poor during the 4 years observed, which had a series of droughts and floods. These led to net financial losses in those years for the demonstration site, but state-wide average farm budget returns did show moderate profits. The results support the merits of agroforestry systems in the upper South to diversify income and reduce financial risks.

Keywords Forests · Crops · Growth and yield · Alley cropping · Economic analyses

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Introduction

The use of agroforestry systems is expanding throughout the world. Tree and crop systems or tree and

pasture systems offer potential advantages to farmers in the United States to provide attractive farming returns while reducing financial risk; to reduce risks from fire or pests; and to help 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 (Nowak et al. 2002; Dagang and Nair 2003). Silvopasture systems are applied to some extent in Florida and the Gulf Coast, but they are not implemented extensively in the U.S. (Pattanayak et al. 2003; Mercer 2004; Workman et al. 2003). Agroforestry systems such as pecans and livestock have been developed longer in the U.S. (Ares et al. 2006), but remain uncommon.

Researchers in Florida (Nowak et al. 2002; Workman et al. 2003; Shrestha et al. 2004; Stainback and Alavalapati 2004), Missouri (Garrett et al. 2004; Udawatta and Godsey 2010) and Mississippi (Husak and Grado 2002) 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, 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: http://www.cefs.ncsu.edu/)—Cherry Farm research site in Goldsboro, North Carolina, in the Upper Coastal Plain. 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. Note that given these practical objectives, especially as information for farm and forest landowners in the U.S. South, this paper presents both U.S. and metric

units throughout to have reference material that is easy to understand for the diverse audiences for this project.

Methods

This paper describes the early results from our project to establish the agroforestry trial, focusing on measuring tree survival and growth, applying models of forest growth and yield, estimating economic returns for three tree species planted at the site, and calculating annual crop yields and returns. 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, including some work in progress now.

Project establishment

The project was developed as an extension and research trial at the CEFS/Cherry farm, which is owned by the state and managed jointly by the North Carolina Department of Agriculture and Consumer Services, 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 North Carolina river systems traversing the Piedmont of North Carolina from the Coastal Plain to the Atlantic Ocean. The site has a complex 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 decades. However, it tended to flood often, making it a good site for considering trees as an alternative crop.

We planted three 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 staggered rows of trees (three lines of trees per tree row) with open land (alleys) for crops—or eventually pasture—between them (Fig. 1). Crop land alleys of 40 ft or 80 ft (12.2–24.4 m) wide were left between the tree rows The tree rows and crop alleys ran approximately east to west, so that the sun could be on the open land as much as possible as the trees grew
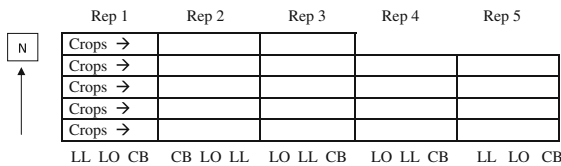
Fig. 1 Representation of Alley Cropping Project Layout, Center for Environmental Farming Systems, Goldsboro, North Carolina. Crop rows varied randomly between 40 ft (12.2 m) and 80 ft (24.4 m). Three tree rows (6 by 6 ft; 1.83 × 1.83 m) in each row; each species in each replication (420 ft/128 m), trees established in blocks across the replications (Rep) as noted at the bottom of the diagram were: *LO* Loblolly pine, *LL* Longleaf pine, *CB* Cherrybark oak

larger. Crop land alleys of 40 ft or 80 ft (12.2–24.4 m) wide were left between the tree rows. The trees were planted in three lines per row, with a diamond shaped 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 m) wide.

The placement of the trees and crop rows was established in a randomized block design across the site, with five replications of each tree/crop variation extending down the field from the upper and drier end to the lower and wetter end. The three tree species also were distributed randomly in blocks of each species 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 of the same species planted per row. We also established check plots with a spacing of 10 ft (3.05 m) by 10 ft (3.05 m) between trees at the lower, wetter end of the field, adjacent to Replication 5 of the main trial. In the check plots, each of the species was planted as a single species 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.

The site was laid out with tape measure, string and flagging, with a spot painted on the ground where each seedling was planted. Seedlings were planted in January 2007 according to the randomized block design by a crew of professors, graduate students and work release prisoners from the adjacent Goldsboro Correctional Center. All the 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 in. blade to open a wide hole for broad roots. Longleaf were planted with a "pottapo-oki" 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 oz per acre (210 g/ha) using a 20 ft (6.2 m) boom, indicating a spraying distance of 5.7 ft (1.75 m) 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. They were planted with conventional tillage on a ploughed field. 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 greatly reduced crop yields as well. Deer browsing in the initial years was almost no problem for the pines and more common on the oaks, but only seemed to nip the lead apical stem growth, not reduce overall vigour. However, browsing intensified on the crops each year as the trees became bigger, and provided more shelter for deer.

Timber growth, yield and financial analyses

In January 2011, after 4 years of growth, we measured the survival, tree trunk diameter and height of the trees. Diameter was measured just above the root collar with calipers; and height with an extension pole. These data were used to calculate survival and growth rates used in timber growth and yield models. At 4 years old, the trees were too young to be used

directly in growth and yield models, but the measurements 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. Because there are not models for growth of trees in alley systems, we used general equations and software packages for whole stands, and then compared them. For future models, 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 partial acre, and likewise for crop yields. We recognise that the "edge effect" should be greater in alley plantings than block plantings, but the growth and volumes so far would be similar in the block plantings based on our field measurements.

For this analysis, we simply compared the growth rates of different species for whole stand forest models based on the best available literature, and with the early data collected on crop yields. We also assumed that there would be no product differences between the three row sets of trees and those in regular forest plantations. In practice, the outer rows of at least loblolly would be valuable mostly for pulpwood due to large branches unless they were pruned, but this could correspond to the thinning assumed for each species, leaving the better interior tree as the sawtimber in the final harvest.

We analysed the returns to these timber investments in real terms (without inflation) using capital budgeting criteria of net present value (NPV), land expectation value (LEV), annual equivalent value (AEV) and internal rate of return (IRR) (Wagner et al. 1995). We used a real discount rate of 4% per year. We analysed the crop returns for each year using farm budget information. We obtained the projected growth rates, input costs, projected timber yields by product class and product prices. Average input costs for planting forest sites were used for the analysis based on Division of Forest Resources (2010) data, as well as North Carolina average coastal plain timber prices from the 4th quarter Timber Mart-South (2010) report. The actual input cost for planting trees on this old crop land was probably less, but we used typical forest planting costs to represent more pervasive state averages. These production functions, input costs and output prices were used to estimate financial returns for each tree species.

Cherrybark oak

The basic information for the cherrybark analysis was generated using the NATYIELD programme developed by Smith and Hafley (1986), which was developed from equations in Schumacher and Coile (1960). The site index used at reference age 50 was 70 ft (21.5 m). 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 spacing of 8 by 10 ft (2.5 × 13.3 m) containing 540 trees per acre (1,334 trees per ha) initially. The average basal area per acre at age 20 was assumed to be 40 ft^2 (3.7 m^2). The basic production data generated by NATYIELD were then used in another hardwood volume equation from the Midwest U.S. (Dale 1973), as a check to produce a second stream of volume projections under the same regime for comparison. This model produced similar results, but was not as relevant as the North Carolina Smith and Hafley (1986) model that we did choose to use.

The cherrybark oak analysis used an 80 year rotation with a pre-commercial thinning in year 30 and a commercial thinning in year 55, with one-third of the basal area in the stand removed each time. In the commercial thinning of 868 ft^3/ac (61 m^3/ha) it was assumed that two-thirds of the harvested biomass would be used for pulpwood, and one-third would be used for sawtimber. In the final harvest of 3,918 ft^3/ac (274 m^3/ha), 100% of the harvested biomass was used for sawtimber.

The prices used for hardwood stumpage prices for the North Carolina Coastal Plain region were $31.41 per ton ($28.56 per metric tonne) for sawtimber, and $4.29 per ton ($3.90 per tonne) for pulpwood. For a capital budgeting analysis, the interest rate of 4% was used to calculate the present value of the two commercial harvests. Costs were $300 per ac ($741/ha) for seedlings and planting, $75 per ac ($185/ha) for chemical treatment in year 1, and $5 per ac per year ($12.36/ha/yr) 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 programme. This assumed the planting rate was 600 trees per acre (1,483/ha), with a site index of 60 ft (18.5 m)

at age 25. Thinning volumes were 475 ft^3 per ac (33.2 m^3/ha) at age 17, with 75% pulpwood ($8.45/ton, $7.68/tonne) and 25% chip-and-saw ($16.89/ton, $15.35/tonne), also based on Timber Mart-South (2010) pine prices for eastern North Carolina. Final harvest volumes were 2,225 ft^3 per ac (155.7 m^3/ha) at a final harvest of age 25, with 23% chip-and-saw wood; 67% small sawtimber ($29.82/ton, $27.11/tonne); and 10% large sawtimber ($61.92/ton, $56.28/tonne). Input costs were $400 per acre ($988.40/ha) for seedlings, site preparation, planting and chemical release, and $5 per acre per year ($12.36/ha/yr) in property taxes.

Longleaf pine

As with the cherrybark oak analysis, the underlying longleaf pine growth in volume was derived using the NATYIELD programme developed by Smith and Hafley (1986). The base scenario was specified as 500 trees per acre (1,236 trees/ha), 70 ft^2 of basal area per acre (16.1 m^2/ha) and a site index of 70 ft (21.5 m) 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 (Lohrey and Bailey 1977; Farrar 1985; Brooks et al. 2006). Each model produced very similar results, so the NATYIELD outputs were used to derive the financial calculations.

The longleaf analysis presented here represents two scenarios: simple timber production and timber production combined with pine straw raking. In many cases, management of longleaf pine will be more complex, including considerations for more intricate pine straw operations, prescribed burning and wildlife habitat benefits. The pure timber production scenario makes for the best comparison with the two similar timber production scenarios for loblolly pine and cherrybark oak. The combined timber and pine straw scenario is becoming more pervasive. Our scenario is a relatively conservative regime of pine straw harvests every 3 years; more aggressive straw management regimes are often proposed.

The longleaf analysis assumed a 40 year rotation with commercial thinning at age 25. During this thinning, basal area was reduced to 60 ft^2 (18.8 m^2/ha) and approximately 10 tons of timber were harvested per acre (22.4 metric tonnes/ha). The material thinned was assumed to be 75% pulpwood ($8.45/ton, $7.68/tonne) and 25% chip-and-saw ($16.89/ton, $15.35/tonne). Final harvest was treated as a clear cut, approximately 54 tons per acre (121.1 tonnes/ha), and consists of 20% chip-and-saw, 50% sawtimber ($29.82/ton, $27.11/tonne) and 30% large sawtimber/poles ($61.92/ton, $56.28/tonne). Longleaf pine prices per unit were the same as for loblolly. Costs included seedlings, site preparation and planting at $325 per acre ($803/ha), chemical herbaceous release at year 1 for $75 per acre ($185.33/ha), and an annual property tax of $5 per acre per year ($12.36/ha/yr). The combination timber and pine straw scenario also includes nine pine straw raking events over the 40 year rotation, beginning at age 16 and occurring every third year thereafter. Each pine straw harvest was assumed to provide $100 per acre ($247.11/ha) in revenue based on conservative estimates available for stands of this age (Longleaf Alliance 2011).

Crop yields and returns

The staff at CEFS harvested the crops each year and measured the yields per plot area, which we then converted to U.S. and metric units. Precipitation at the Goldsboro Cherry Farm research site was obtained from the State Climate Office of North Carolina (2011a). The data for soybean and corn planting costs for conventional tillage were obtained from NC State University (2011a, b, c, d) agricultural extension farm budget data. Average North Carolina corn prices were obtained from the same source for all scenarios. North Carolina soybean prices were obtained from the NC State University data for 2009 and 2010, but their data were lacking for 2007, so we used the United Soybean Board (2011) national soybean prices.

These data were used to estimate net annual cash flows. However, unlike the forest analyses, these were not converted to a capital budgeting analysis due to their negative returns and wide variability over the first 4 years. Instead, scenarios with different and better cases were calculated as comparisons, based on the best yields, in Replication 5 and the costs and prices in 2010. These best scenarios were at the crop yields rates of 30 bushels per acre (2,000 kg/ha) for soybeans and 112 bushels per acre (6,920 kg/ha) for corn. These two best case scenarios on the Goldsboro site actually matched the NC State University (2011a, d) average North Carolina yields in their farm budgets for 2010,

at 110 (6,800 kg/ha) bushels per acre of corn and 35 bushels per acre (2,335 kg/ha) for soybeans, so they should be representative. This approach provided a range of scenarios for comparison between actual, measured crop yields and annual returns versus the discounted value of the projected timber returns.

Results

Results from the tree inventories, timber growth and yield projections, crop yield and costs data and financial calculations are summarised below. First, it is worth noting that the weather varied considerably in the first 4 years since the trial was established. This reduced the crop yields substantially, but did not seem to affect tree survival or growth much.

Precipitation

Precipitation at the Goldsboro Cherry Farm Research site varied widely in the 4 years since planting (Table 1). The first year of planting, 2007, was very dry at the site, with only 13.5 in. (340 mm) of rain falling from March 1 to August 30. The second year (2008) had 23.9 in. (600 mm). Rainfall was 19.9 in. (505 mm) from March to August 2009 and 12.7 in. (323 mm) 2010. In addition there were floods of 8.5 in. (216 mm) in September 2008 and 12.7 in. (322 mm) in September 2010.

Table 1 Growing season precipitation, March 1–September 30, Cherry research farm and South Central Coastal Plain of North Carolina

Year or period	Cherry research farm precipitation (in.)	Central coastal plain region precipitation (in.)
2007	13.5	19.8
2008	23.9	27.2
2009	19.9	34.8
2010	12.7	25.0
Mean, 2007–2008	17.5	26.7
Mean, 1960–2010	Na	28
Maximum, 1960, 2010	Na	36
Minimum, 1960–2010	Na	18.6

Note inches × 25.4 = mm

Source State Climate Office of North Carolina (2011a, b)

These monthly weather variations at the Cherry Farm weather station can be compared with the 50-year trends for the Central Coastal Plain region (State Climate Office of North Carolina 2011b). However, the averages for the Central Coastal Plain were somewhat different than the specific rainfall at the Cherry Research Farm, indicating the variability in storm precipitation even in 1 year among small micro-regions.

The annual Central Coastal Plain and Cherry Farm precipitation data from March 1 to August 30 are shown in Table 1. The data indicate that the four summers at the Cherry Research Farm were dry, with all of them falling below the 50-year average for the Central Coastal Plain. In addition each year also had less rain on the Cherry Research Farm specifically than in the Central Coastal Plain region as a whole. Furthermore, in 2007 and 2010, the Cherry Research farm had only about 13 in. (330 mm) of rain from March to August, which was only 70% of the worst rainfall year of the last 50 years, and less than half of the average for the 50 year period. These extreme droughts desiccated the crops in both years.

Tree growth

The results from the tree survival and growth measurements at age 4 in January 2011 are summarised in Table 2. 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 tree diameter in Replication 5 was greater (α = 0.01) than in the other replications. Thus we summarised the data for the totals of all Replications 1–5; for Replications 1–4; for Replication 5; and for the check plots.

Survival rates were 93% for cherrybark oak, 88% for longleaf pine and 97% for loblolly pine. 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, especially at the dry end of the field, but were surviving. Furthermore, they grew rapidly during the fifth year in the wet sites, but we have not re-measured them yet.

Table 2 Survival, tree trunk 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%
Trunk diameter (in.)			
All replications	3.2	2.1	1.0
Replications 1–4	2.9	2.0	1.0
Replication 5[1,2]	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

Note inches × 2.54 = cm, and feet × 0.305 = m

[1] All diameters and heights between species were statistically different ($\alpha = 0.01$)

[2] For longleaf pine and cherrybark oak, the mean diameter in Rep 5 is statistically different from the mean of the check plots ($\alpha = 0.01$). For loblolly this difference was significant at $\alpha = 0.10$

[3] The mean height in Rep 5 is statistically different from the mean of the check plots for all species ($\alpha = 0.01$)

Across all replications, average tree diameter at ground level was 1.0 in. (2.54 cm) for cherrybark oak, 2.1 in. for longleaf (5.33 cm) and 3.2 in. (8.13 cm) for loblolly. Heights averaged 4.6 ft (1.4 m) for cherrybark oak, 5.2 ft (1.6 m) for longleaf pine and 10.4 ft (3.2 m) for loblolly pine. All the values among the trunk diameter and height among species were significantly different ($\alpha = 0.01$).

Results varied by location in the drier or wetter ends of the field. Longleaf grew approximately 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 least height growth and worst survival 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.

Projected timber growth, yield and financial returns

Table 3 summarises the management regimes, projected growth and harvests, as well as the financial results for the three tree species. Loblolly pine grew the fastest according to the growth and yield equations, at an average of 108 ft³/ac/yr (7.6 m³/ha/yr). Longleaf pine grew at an average of 71 ft³/ac/yr (5.0 m³/ha/yr) and cherrybark oak at 61 ft³/ac/yr (4.3 m³/ha/yr). These growth rates and shorter rotations favour loblolly, then longleaf, then oak.

Loblolly pine had the best timber returns at a 4% discount rate, earning a NPV of $493 per ac, LEV of $789 per ac ($1950/ha) and IRR of 7.2%. The timber-only longleaf pine analysis had a negative NPV of −$49 per acre (−$121/ha) and LEV of −$61per ac (−$151/ha). With pine straw harvests, longleaf pine returns became positive, with a NPV of $274 per ac ($677/ha) and LEV of $346 per ac ($855/ha). Both cases assumed an initial establishment cost of $325 per ac ($803/ha). Cherrybark oak also had a negative NPV and LEV at the 4% discount rate, given the initial cost $400 per acre. The IRRs were 3.7% for the timber only longleaf stand, 5.5% with pine straw and 1.9% for the cherrybark oak. Costs should be less for planting on open agricultural fields than the generic forest replanting averages we used based on cut-over forest sites, 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—1,280 trees per acre (3,163/ha), but on only a portion of the area. The brushier form of open grown alley cropping trees may differ from those in pure plantations, necessitating pruning to ensure good timber trees and products. This would add costs, perhaps for little added final sales value compared to timber in a forest plantation, thus reducing net returns from those we estimated here. Based on 5 years of growth—through 2011 now—the loblolly trees in the alleys appear to have more branches than a plantation tree would, but longleaf has not branched much, and the more thrifty oaks look full of branches in the woods, the check plots and the alley plantings.

The financial results vary when longleaf pine straw potential is considered. And the cherrybark oaks will offer greater mast and wildlife advantages.

Table 3 Growth and capital budgeting results for three species for timber production management regime at a discount rate of 4%

Species	Rotation age (yrs)	Harvest years	Total projected volume cut/mean annual increment (ft³/ac)	Net present value ($/ac)	Land expectation value ($/ac)	Annual equivalent value ($/ac)	Internal rate of return (%)
Cherrybark oak	80	55 and 80	4,846/ 61	−360	−376	−15	1.9
Longleaf pine–timber only	40	25 and 40	2,826/ 71	−49	−61	−2	3.7
Longleaf pine–timber and pine straw	40	24 and 40	2,826/ 71	274	346	11	5.5
Loblolly pine	25	17 and 25	2,700/ 108	493	789	32	7.2

Note ft³/ac × 0.06997 = m³/ha

$/ac × 2.471 = $/ha

Furthermore, as noted on our soils, while loblolly pine grew better everywhere, its advantage was 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 and the adjacent agricultural land use has yet to be determined. Similarly, tillage of the crop alleys will damage tree roots, although no-till drill planting could reduce this impact. 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) and reduced soil compaction over many years from less area being frequently trafficked. Changes from alley cropping to alley grazing with livestock will also lead to new production interactions.

Crop yields and cash flows

The floods and droughts on this site with sandy soil on the high end and wetland soils on the low end produced marginally acceptable crop yields for the entire field in only two of the 4 years and almost none in 2010 (Table 4). As noted above, the trees, on the other hand, grew relatively well. The site averaged only 12 bushels per acre (800 kg/ha) of soybeans in both 2007 and 2009; 51 bushels per acre (3,151 kg/ha) of corn in 2008; and 20 bushels of corn per acre (1,236 kg/ha) in 2010. These yields are quite low compared to state and national averages. The wet end of the field in Replication 5 was better for crops, at 30 bushels per ac (2,002 kg/ha) of beans in both years; 112 bushels per ac (6,919 kg/ha) of corn in 2008; and 52 bushels per ac (3,212 kg/ha) in 2010. Nevertheless, the crop yields were poor given the weather we experienced since 2007.

Table 4 also summarises the simple farm budget of costs and returns for each year, and for the best case, which is represented by the growth in Replication 5 in the best year, at the prices for 2010, which were a modern day record high. These two scenarios represent what one might expect in better years, on better soils with more organic material. The average scenarios for 2007 through 2010 of course are worse. We could calculate even worse scenarios based on awful average crop yields in Reps 1–4 (8 bushels of beans per acre each year; 14 or 38 bushels of corn per acre). But this seems pointless given their extremely poor results.

The average net returns for all the actual cases for Reps 1–5 were negative, ranging from −$107 per acre

Table 4 Crop yields, average costs, prices, and returns per acre by year and best scenario

Year	Crop	Average yield (bushels/ac)	Average cost ($/ac)	Prices per bushel	Total sale price ($/ac)	Net returns ($/ac)
2007	Soybeans	12	228	10.10	121	−107
2008	Corn	51	299	3.50	179	−120
2009	Soybeans	12	228	9.59	115	−113
2010	Corn	20	411	4.35	87	−324
Best beans, Rep 5, 2007 and 2009[1]	Soybeans	30	228	10.40	312	84
Best corn, Rep 5, 2008[1]	Corn	112	411	4.35	487	76

Note bushels of soybeans/ac × 66.7 = kg/ha; bushels of corn × 61.8 = kg/ha; and $/ac × 2.471

[1] Best yields based on the year they occurred in Rep 5; net returns based on 2010 costs and prices

(−$264/ha) to −$324 per acre (−$800/ha). The best, hypothetical cases at 2010 costs and prices and high yields for soybeans and corn were better, at positive $84 per acre ($207/ha) for soybeans and $76 per acre ($188/ha) for corn. These yields and prices were still small compared to the large yields and returns reported in the Midwest, or even in rich organic soils in some locations in eastern North Carolina. Corn and bean prices have dropped some in 2011, so the best cases still might be uncommon.

We did not calculate capital budgeting results for the 4 years of crop returns alone, because they were both so brief and so poor that it did not seem useful. One could compare the annual losses from the crops with the Annual Equivalent Value (AEV) from the timber projections, at the 4% discount rate. This of course only indicates that it is better to make a modest amount of returns from trees on an annualized basis, or only lose a small amount, rather than lose a large amount on crops each year. The discounted values of crops in a capital budgeting analysis at 4% would mean that they lose more than summarised above, because costs would be incurred at the start of the year, and returns received at the end of the year.

Discussion and 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, with high survival rates. The trees had average survival rates of 88% for longleaf pine, 97% for loblolly pine and 93% for cherrybark oak after 4 years of floods and droughts. In fact, the trees prospered more than the crops, which were almost failures 3 of the 4 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 alone. If silvopasture were implemented, in the early years the trees will need to get bigger to minimise damage, and alley cropping could occur as we have done, or fencing would need to be established to protect the trees.

The financial returns tracked the tree and crop yield growth projections. Loblolly pine had the greatest timber land expectation value and annual equivalent value at the 4% discount rate, at $789/ac LEV and $32/ac/yr AEV. Longleaf pine's returns were positive when pine straw revenue was included, generating and NPV of $274/ac and IRR of 5.5%. The LEVs and AEVs for timber-only longleaf pine and cherrybark oak were slightly negative at the 4% discount rate, and they had IRRs, of 3.7 and 1.9%, respectively. The CEFS farm field average crop returns based on these costs, yields and prices would not be positive in any of these years, nor would they have a positive IRR in any case.

The best farm returns would have moderate returns and positive IRRs. This would not be representative of the Goldsboro site in the 4 years measured, but did match the state average farm budgets (NC State University 2011a, d). Of course, farmers will both focus on planting crops on good sites and hope for good years of adequate rainfall and high prices. But our small case at least suggests these hopes are not often realised on poor sites, even though this site has been farmed for decades. Perhaps this site and similar

ones with poor productivity and resiliency to weather extremes could be programmed for silvopasture, and better sites might be reserved for long-term alley cropping.

The climate records for the 4 years analysed indicate that all 4 years at the Cherry Farm site were drier than the 50 year Central Coastal Plain average during the growing season, and actually included the two driest summers on record (2007 and 2010). This led to very poor crop yields, but no observable adverse effect on the trees. If indeed climate change occurs and is associated little summer rainfall and high temperatures, agroforestry systems with crops, or particularly livestock, do appear to be more viable to diversify farm risk and ensure at least some timber returns to offset frequent years of crop losses.

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 check plots had the largest tree trunk diameters and heights, but this seemed to be largely a function of the better, wetter sites where they were planted, 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 potential for other products and ecosystem services, which could reduce this financial advantage for loblolly. On the other hand, the need for pruning might reduce or increase net returns from the alley tree planting system.

The alley crop and potential future livestock interactions will make this agroforestry trial and financial results more complex. Loblolly pine grows well and fast, but shades the crops sooner and generally has a wide spread and bushier crown than longleaf. Cherrybark oak growth often starts slow, but may be very productive on deep red river bottom sites in the longer term, and be hardier as the alley cropping system moves from trees and crops to trees and livestock. It also may provide better habitat for wildlife species for hunting as well. Furthermore, longleaf pine can grow to a much longer rotations of about 80 years, and can be used as habitat for the

endangered species of red-cockaded woodpeckers (RCW; *Picoides borealis)*, which may be environmentally important, and may offer opportunities to receive payments for those environmental services. It is not known if RCW will inhabit agroforestry sites, but the savannah system approach would seem to be favourable for conversion to longleaf pine, wiregrass (or other grasses favourable for agriculture) and RCWs later in the rotation—especially at the narrower crop alley planting rates.

Other management regimes and planting patterns also may be desirable. In initial extension visits to the site, some farmers suggested that six rows of longleaf would be better for straw raking and production. We also noted that deer browsing on crops was worse near the border of the tree alleys, which provided them shade and shelter. This also might favour fewer, broader alleys to minimise this edge effect. Other farmers felt that they would prefer crop alleys greater than 40 ft as a minimum. One person noted that actually having the mix of three species, including hardwoods, might be particularly good for generating revenue from diverse types of game species hunting, such as deer, quail and migratory birds.

A forester felt that longleaf pine could do well in the wetter end as well as the drier, but agreed that this would take more competition control and management interventions to succeed. Our tree growth results so far only indicate what would occur with good establishment practices, but no subsequent forest stand treatments yet. This minimal management is probably typical for farm landowners, especially absentee owners, but more active management could improve timber management and allow different species composition to grow well.

This demonstration in North Carolina indicates that agroforestry alley cropping can be established and succeed in the upper South, but it does not dictate the only management regime possible. The relative success of the agroforestry demonstration, and moderate economic returns, does buttress the findings of other research results reported in the deep South. More outreach and dissemination of the prior research and our efforts might help promote the merits of this approach farm and forest landowners. These specific alley cropping or silvopasture management alternatives will vary by landowner objectives and the land characteristics. Initial demonstrations at the site have generated considerable interest and lively discussions,

so it is achieving its outreach as well as research objective.

The trial does indicate that each of these tree systems could survive and provide some growth and modest financial returns for an agroforestry system—perhaps as much or more than pure crop systems on poor sites. Given the small site location, complex mix of soils and extreme weather conditions experienced to date, the tree component seems to offer a very attractive alternative to crops alone, and silvopasture systems may be most useful once the trees grow larger. We will continue to measure crop yields and tree growth and perform future financial calculations based on actual yield as the project progresses and trees mature. We look forward to more demonstration, research and education about these systems as we manage and monitor the first modern planned and implemented agroforestry system in North Carolina.

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