herbicide concentration. Inconsistent readings require rechecking amounts of herbicide and water added and adjusting the mixture as needed. Using this procedure, one cannot differentiate whether herbicide concentration, surfactant concentration, or both are in error. Because herbicide concentrations affect conductivity much more than surfactant concentrations, variations usually involve incorrect amounts of herbicide or water rather than incorrect amounts of surfactant.

The use of the conductivity method provides additional quality control to operational spray programs. The method is accurate, easy, quick, and its use does not impair operational efficiency. Operational delays occur only when mixing errors are identified and corrections are made. □

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Red-Cockaded Woodpecker Habitat Management and Longleaf Pine Straw Production: An Economic Analysis[1]

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*ABSTRACT. This paper contains an economic analysis of shelterwood management of longleaf pine (*Pinus palustris Mill*) with markets for both timber and pine straw. It was found that extended rotations required for red-cockaded woodpecker (*Picoides borealis*) habitat, while not optimal, are better when pine straw is also a market product than when considering timber alone. Rotation ages were fixed at 60, 80, 100, and 120 years to provide red-cockaded woodpecker habitat. A single thinning is included with variable timing and intensity. Intensive site treatments are also included to control litter, grasses, hardwood, and brown spot disease. An equation for pine straw yield as a function of basal area is presented. Pine straw may increase soil expectation value by more than 230% over that provided by timber alone.*

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The red-cockaded woodpecker is an endangered species that requires mature pine for both foraging and nesting habitat. However, preferred timber harvest ages for southern pines are usually less than 40 years. This simple observation leads to the impression that economic timber management and red-cockaded woodpecker habitat are mutually exclusive. However, longleaf pine straw is another forest product with a bustling market, and the production of pine straw seems compatible with red-cockaded woodpecker habitat management.

Every year longleaf pine covers the ground with a new layer of needles. Valued as a seed-free weed mulch, these needles are raked, baled and marketed for use by farmers, nurseries, and landscapers. As one of the most valuable products of the longleaf pine, the needles offer the land owner a biennial source of income (White et al. 1988). Reported yields are around 65 to 80 bales (62 pounds/bale) per ac per year, with reported returns of from $80 to $160 per acre per year.[2] If stands of longleaf pine and access to a pine straw market exist, long rotations needed for woodpecker habitat are economically justifiable.

Managers interested in red-cockaded woodpecker habitat and concerned with monetary income should consider longleaf pine straw as a potential opportunity. To investigate this opportunity we evaluated economic returns from longleaf pine stands under shelterwood management with rotations lengths extended to accommodate woodpecker habitat in areas having markets for both timber and pine straw. The results suggest ways to manage a stand for commercial value and also provide woodpecker habitat.

SHELTERWOOD MANAGEMENT SYSTEM

A shelterwood system for longleaf pine is a preferred method

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[2] Longleaf Pine Training Seminar, North Carolina Forest Service, Sept. 7, 1988.

for obtaining natural regeneration because it provides a seed source, lowers brown spot needle blight infection rates, and reduces regeneration times (Croker 1969). A shelterwood system is also preferred for perpetuating an existing stand of longleaf pine because of the high uncertainty and cost involved in artificial regeneration.[3] In one comparison of artificial regeneration methods and shelterwood cutting for longleaf pine, a shelterwood system resulted in higher soil expectation values (SEV) than artificial methods.[4]

Our analysis compares four rotations. The main criterion for comparison is the soil expectation value (SEV). Rotation age was set at either 60, 80, 100, or 120 years. These rotation lengths were selected so that the comparison could be made over a range of ages appropriate for woodpecker habitat. Going beyond 120 years would also be outside the range of the growth and yield model used. We assumed that 60- and 80-year rotations provide only foraging habitat, and 100- and 120-year rotations provide both foraging and nesting habitat. The timing and intensity of a single thinning is allowed to vary.[5] Thinning age and intensity were varied to help mitigate the effect of extended rotations.

The analysis starts with a 7-year-old longleaf sapling stand just after shelterwood overstory removal and ends with a single-stage shelterwood overstory removal (Figure 1). The overstory is removed 7 years after the shelterwood cut to allow for adequate stocking of seedlings [Wahlenberg (1946), Boyer (1963) and White et al. (1988)]. Seed bed preparation is crucial for natural regeneration of longleaf. If done too early, litter and grass will accumulate reducing germination (Croker 1969). We assumed that seed bed preparation is done immediately after the shelterwood cut and is followed 3 and 6 years later by two prescribed burns. These burns help control litter, grass, hardwoods, and brown spot disease. Another burn is scheduled after thinning to control litter, grass, and hardwoods. Chemical treatment of hardwood is scheduled every 10 years starting 10 years after shelterwood removal. Better sites may require more frequent burning and/or chemical treatment.

Hardwoods and early longleaf density are assumed to be controlled by the burning and chemical treatments. Early thinning around age 25 to 30 to alleviate possible overstocked conditions may also be desirable. However, a

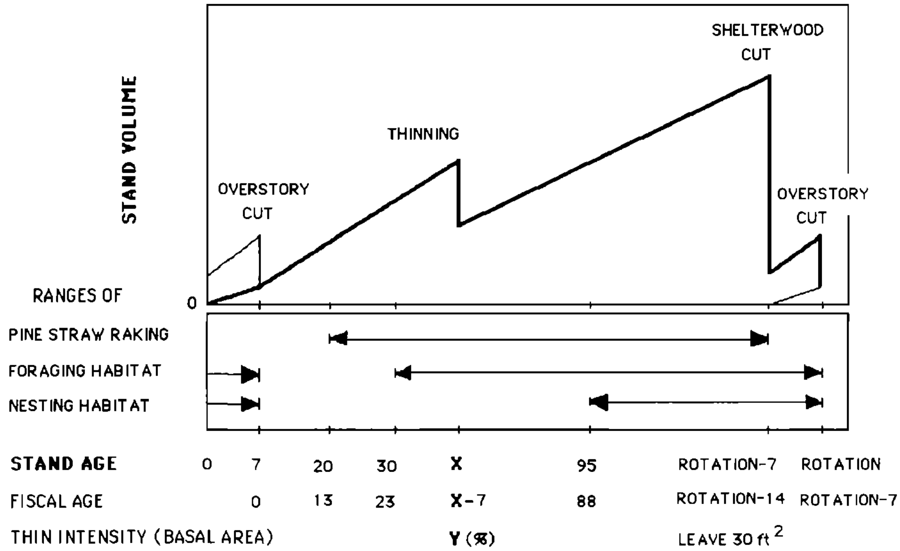

Figure 1. A schematic diagram of one shelterwood rotation. Stand age is the physical age of trees and fiscal age is the time since overstory removal. Rotation length was fixed at stand age 60, 80, 100, and 120. Thinning time, Y, *and intensity,* X, *are variables that were adjusted to find the "best" thinning schedule.*

Table 1. Financial and production data used in the analysis of longleaf pine shelterwood systems. Although potentially significant, timber marking costs and per acre management costs are not included.

	Annual interest rate 4%	
	Costs per unit volume	
	Sawtimber	Pulpwood
Stumpage	\$205/mbf	\$43/cord
Logging	\$0.08/ft³	\$0.03/ft³
Transportation	\$0.02/ft³	\$0.03/ft³
	Treatment data per unit area	
	Cost	Execution times
Site preparation	\$60/ac	
Burn	\$15/ac	Year 3, 6, and after thinning
Chemical	\$ 9/ac	Every 10 years
	Pine straw data	
Market price	\$3.25/bale	
Baling cost	\$1.70/bale	
Weight	62 pounds/bale	
Raking efficiency	80% of needle production is recovered	
Raking frequency	Every other year starting at age 20	

[3] Ibid.

[4] Ibid.

[5] Optimal thinning time and intensity are determined by use of a nonlinear programming formulation discussed by Roise (1986).

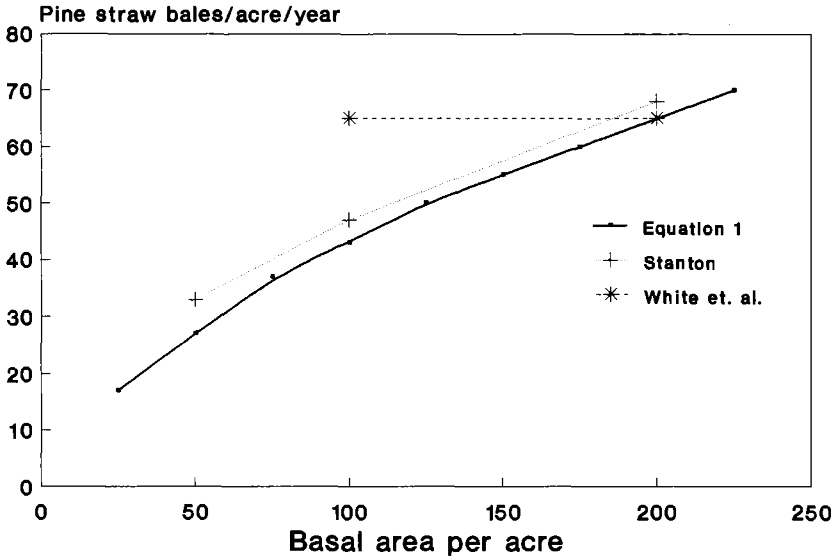

Figure 2. Comparison of pine straw yield predicted by Equation (1) and yield reported by White et. al. (1988) and Stanton (1988).

prescribed early thinning was not included in this analysis. The shelterwood cut removes all but 30 ft^2 of basal area. We assumed that the remaining trees are properly spaced for seed dispersal. Pinestraw raking begins at age 20 and continues every other year until the shelterwood cut. Table 1 summarizes price and cost data used in the analysis.

PINE STRAW YIELD MODEL

Gresham (1982) reported litter fall rates for longleaf pine based on observations of basal area and litter fall. His data were for stands greater than 15 years old. This data set was used to estimate coefficients for the following pine straw production equation:

$$Y = -788.78 + 413.1076(BA)^{1/2} \quad (1)$$

where Y is pounds per acre per year of pine needle production and BA is square feet of basal area.

Other data on pine needle litter fall have been reported. Equation (1) is compared to other empirical observations of White et al. (1988) and Stanton (1986), in Figure 2. White et al. (1988) reported a constant value of 65 62-pound bales per acre per year in fully stocked stands of 90 or more square feet basal. Equation (1) predicts lower yields except at densities above about 200 square feet basal area. Equation (1) predicts yields similar to the empirical estimates reported by Stanton (1986). He reported annual production from about 35 to 68 (62-pound bales) with an average of about 48 bales. In Figure 2, the data attributed to Stanton (1986) are approximated from his report. Thus, equation (1) provides a comparatively conservative estimate of yields compared to other sources.

Timber Growth and Yield Model

Timber yield estimates are based on the model by Schumacher and Coile (1960) using two assumptions: (1) Initial basal area for the 7-year-old stand immediately after overstory removal is determined using the equation reported by Furnival (1957), and (2) there is no growth response from thinning. Thinning serves only to decrease density and provide an intermediate source of timber income during the extended rotation.

It should be pointed out that the impact of pine straw raking on growth and of having only pine roots in the root zone over such long time periods is unknown. There may be a significant impact, which we have not considered, on the projected timber and pine straw yields as well as other site characteristics. In addition, we have assumed that the desirable condition for red-cockaded woodpecker habitat is mature pure pine stands. Yet, it is not certain that woodpeckers would consider the proposed densities and the relatively unusual forest floor conditions suitable habitat.

RESULTS

Pine straw is predicted to contribute considerably more to the

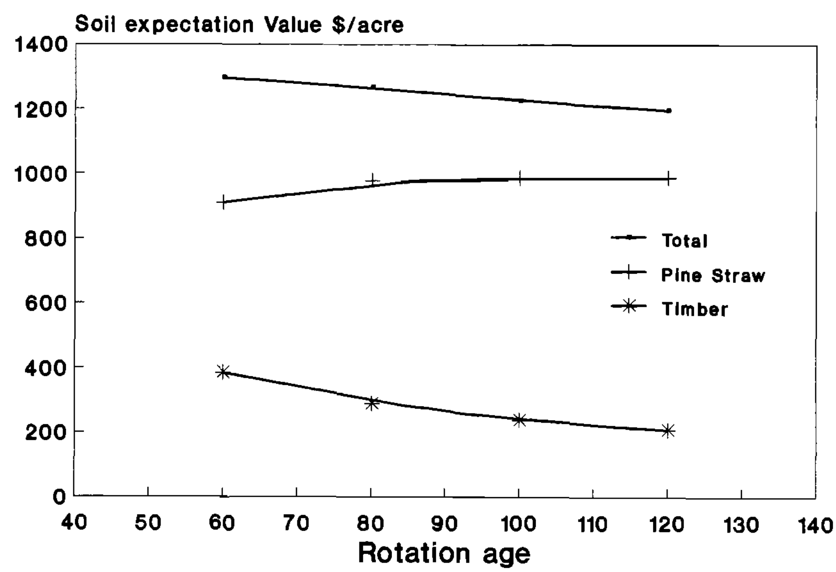

Figure 3. Soil expectation value versus rotation age. Top line is total SEV. Middle line is the pine straw only SEV. Bottom line is timber only SEV.

value of the land than timber (Figure 3). Thus, it is possible to grow longleaf pine economically over the long rotations needed to produce red-cockaded woodpecker habitat. However, the slope of both total and timber SEV values are negative, implying that the best economic rotation occurs sometime before 60 years. In contrast, the slope of pine straw SEV values is relatively flat but positive. Rotation ages less than 60 years were not considered because they would be too short for red-cockaded woodpecker nesting habitat. Ages over 120 years were not considered because they are too far outside the range of the growth and yield prediction equations. Also, when maintaining a stand over long time periods mortality may start to reduce pine straw yields and make understory control much more expensive.

The location of the optimal rotation age is highly dependent on market (Roise et al. 1988). If the pine straw market was weak, timber's effect would dominate. Conversely, if the timber market was weak, pine straw's effect would dominate. Thus, any decision on a proper rotation length depends on the specific situation.

Scheduling details from the four rotations are listed in Table 2 and associated volumes in Table 3. Note that pine straw production averages from 26 to 28 bales/ac/yr over the entire rotation, and from 36 to 41 bales/ac/yr over the years when raking is possible. This is below the average amounts reported by other researchers and is a result of the relatively low basal areas remaining after thinning. The timing and intensity of thinning is a result of the model and optimization process described in the paper. Given fixed-rotation age, the optimization process adjusts thinning time and intensity to find a balance between timber and pine straw values to achieve the highest combination of both.

Table 3. Timber volumes from the four rotations. Revenue was calculated with the mbf and cord values. Harvesting cost was calculated with the cubic foot (cf) values.

Rotation length	Cut	Stand age	Saw timber CF	Saw timber mbf	Pulp wood CF	Pulp wood Cords	Net revenue $/ac
60	Thin	48	1090	4.0	188	2.2	752.19
	Shelter	53	1081	4.1	112	1.3	748.29
	Removal	60	1455	5.8	80	1.0	1048.22
80	Thin	52	1533	5.8	181	2.1	1057.63
	Shelter	73	1438	6.2	39	0.5	1107.47
	Removal	80	1617	7.2	30	0.4	1292.77
100	Thin	52	1771	6.6	209	2.5	1221.69
	Shelter	93	1700	7.9	20	0.2	1424.83
	Removal	100	1697	8.1	16	0.2	1458.33
120	Thin	52	1898	7.1	224	2.6	1309.58
	Shelter	113	1962	9.6	13	0.2	1736.77
	Removal	120	1746	8.6	10	0.1	1571.34

Table 2. Fixed rotation age versus stand conditions throughout rotation. Longleaf pine site index 70 base age 50. The initial stand conditions at age 7 years was 100% stocking, with 12,600 trees per ac, and 1.42 ft² of basal area.

	Rotation age 60	80	100	120
Before thinning				
Stand age	48	52	52	52
Stocking	100	100	100	100
Basal area	111	115	115	115
Ave. dbh	9.4	10.0	10.0	10.0
After thinning				
Stocking	55	44	35	30
Basal area	61	50	40	35
Before Shelterwood cut				
Stand age	53	73	93	113
Stocking	58	55	55	58
Basal area	67	71	75	81
Ave. dbh	10.1	12	13	14
After Shelterwood cut				
Stocking	26	23	22	21
Basal area	30	30	30	30
Before Overstory Removal				
Stand age	60	80	100	120
Stocking	30	27	25	23
Basal area	37	35	34	33
Ave. dbh	11	12	13	14
Pine Straw Production				
Total bales	1367	2055	2750	3390
Ave. bales/yr	28	26	28	28
Ave. bales/productive yr	41	39	38	36
Soil expectation value				
Timber	386	290	239	209
Pine straw	912	978	988	989
Total	1298	1268	1227	1198

CONCLUSIONS

Profitable long rotation-age forestry can be practiced to maintain red-cockaded woodpecker habitat provided a sufficient basal area of longleaf pine exists to regenerate by shelterwood cutting and provided pine straw is a marketable product. The optimal rotation age considering both timber and pine straw is some age less than 60 years. The optimal rotation for timber alone is also less than 60 years. However, the optimal rotation for pine straw alone is greater than 120 years. How much greater is an open question. Potential income from pine straw may exceed that from timber production. Desirable woodpecker habitat can be profitably maintained in longleaf pine by using a shelterwood system and marketing pine straw as well as timber.

If a site does become colonized during these long rotations we propose that the decision be made not to harvest and to continue raking pine straw for as long as is physically possible. Continuing the trend shown in Figure 3, there is a gradual loss in SEV for extending rotations beyond those analyzed. However, cash flow from the stand would be fairly constant for as long as the stand of longleaf pine and a market for pine straw survives.

If a site does not become colonized during these long rotations and a harvest decision is made. We suggest that the continuity of available nesting and foraging habitat need not be lost. Continuity of habitat can be achieved by the proper scheduling of harvests (Roise et al. 1990). □

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Compatible Tree-volume and Upper-Stem Diameter Equations for Plantation Loblolly Pines in the West Gulf Region[1]

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*ABSTRACT. Equations are presented for predicting inside bark (ib) or outside bark (ob) cubic-foot volume to any ob diameter limit, or the ib or ob diameter at any given height, of loblolly pine tress (*Pinus taeda *L.) growing in thinned or unthinned plantations in the West Gulf States region. The model formulation and simultaneous estimation technique utilized ensure that the volume and stem profile equations are compatible and the parameter estimates are statistically efficient. The 230 sample trees used to develop the equations were from central Louisiana plantations and ranged in diameters at breast height (*D*) from 1.3 to 20.8 in. in total height (*H*) from 16 to 96 ft, and in ages from 9 to 55 yr. Significant differences in stem profile between trees of the same* D *and* H *in unthinned and thinned plantations suggest that separate cubic-foot volume and upper-stem diameter prediction equations should be used*

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Loblolly pine (*Pinus taeda* L.), by being the most widely planted commercial softwood species in the South, has gained attention for the development of a new growth and yield prediction system (Baldwin and Feduccia 1987). As part of this project, it was necessary to develop stem profile functions, and total and partial weight and volume equations for trees from representative thinned and unthinned stands on cutover sites in the west Gulf States region. The weight equations were published separately (Baldwin 1987) because the weight data set only comprised a subset of the volume and stem taper data used in this study.

New equations were needed because those already published were inadequate for general use

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