Effects of Combination Plowing on the Survival and Growth of Loblolly Pine

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Abstract

Six trial sites were established in the Southeast United States to investigate the effect of a combination of surface and subsurface tillage on survival and growth of loblolly pine (*Pinus taeda* L.). The tillage was conducted in a single pass using a 3-in-1 combination plow. Seedling survival 1 year after planting was significantly greater in tilled plots compared with nontilled plots at two of the six trial sites. The increase in survival at these two sites averaged 10 percent. Seedling growth after 6 years was significantly greater in tilled plots than nontilled plots at three of the six trial sites. The volume response to tillage at 6 years on the most responsive site was equivalent to an annual growth increase of 29.8 ft^3 per ac per yr (2.1 m^3 per ha per yr) more than the nontilled control. In light of the small and variable response on these well-drained upland sites, it is unlikely that this costly operation is warranted.

Introduction

Site preparation prescriptions in pine plantations in the Southeastern United States are designed to create soil conditions favorable for survival and growth of seedlings (Lowery and Gjerstad 1991). Many plantations in the Piedmont and Upper Coastal Plain in the South are established on sites that were previously used for row crop agriculture (Fox et al. 2007). Because of the severe erosion that accompanied row crop agriculture, the clayey B horizon soil, which has high bulk density, is now incorporated into the Ap horizon. Tillage treatments are frequently used on these upland sites to decrease bulk density and increase aeration porosity of the soil, thereby allowing seedling roots to proliferate through the soil (Gent et al. 1984, Morris and Lowry 1988). Tillage also soil increases water and nutrient availability to the planted seedlings because it increases rainfall infiltration and organic matter decomposition and decreases hardwood competition (Campbell et al. 1974, Morris and Lowery 1988, Wheeler et al. 2002, Schilling and Lockaby 2004). Previous trials established in the Southeast United States to examine the effect of tillage on loblolly pine (*Pinus taeda* L.) seedling growth have reported growth responses ranging from 15 to 90 percent (Wheeler et al. 2002, Carlson et al. 2006).

Tillage equipment, such as the 3-in-1 combination plow (figure 1), was developed to allow surface tillage and deep ripping to occur in a single pass in hopes of cost-effectively altering soil physical properties (figure 2) and thus more

Figure 1. Typical 3-in-1 combination plow used for tillage showing disks for surface tillage and ripping shank for subsoil tillage. (Photo by Forest Productivity Cooperative, North Carolina State University, date unknown)

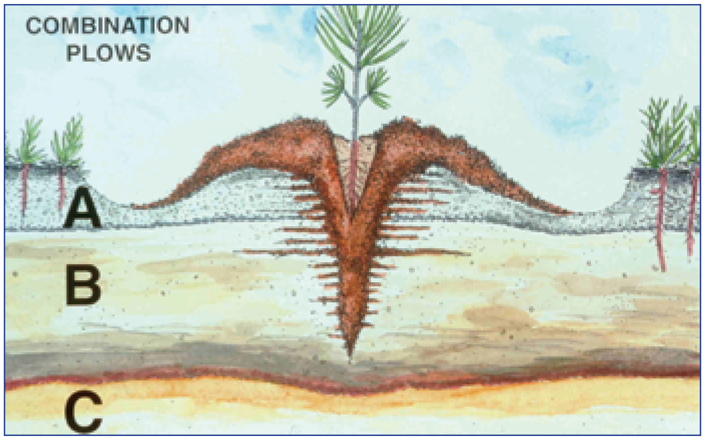

Figure 2. Effects of tillage with 3-in-1 combination plow on the A, B, and C horizons in a typical soil profile. (Illustration courtesy of Weyerhaeuser Company)

consistently increasing seedling growth. This article describes results from a trial that was established across the Southeast United States to compare seedling survival and growth between two treatments—a nontilled control and a combination of surface and subsurface tillage in a single pass using a 3-in-1 combination plow. The study was established at six locations and seedling response was monitored for 6 years.

Methods

Six trial sites were established between 1994 and 1998 in the Piedmont and Upper Coastal Plain in the Southeastern United States. Sites had well-drained soils and relatively shallow topsoils over heavy clay subsoils (tables 1 and 2). A control treatment using no tillage was compared with a tillage treatment in which subsoiling and surface tillage were done in a single pass of a 3-in-1 combination plow (figures 1 and 2). Tillage was done using either a Savannah™ Model 310 or 450 3-in-1 combination plow, which tilled the surface soil to a depth of approximately 12 in (25 cm) and the subsoil to a depth of approximately 24 in (50 cm). Each treatment was replicated twice at study 3801, three times at studies 0101 and 4501, and four times at the remaining three sites (0601, 2801, and 3201). Individual measurement plots ranged in size from 0.07 to 0.17 ac (0.03 to 0.07 ha) and averaged 0.10 ac (0.04 ha). A treated buffer of 30 to 40 ft (9 to 12 m) surrounded each measurement plot.

All trials were hand planted with 1-0 genetically improved loblolly pine seedlings. The number of trees in each treatment plot ranged from 48 to 77 and averaged 61 trees. Measurement plots in four studies (0101, 3201, 3801, and 4501) were double planted (i.e., two seedlings were planted approximately 6 in [15 cm] apart at each planting spot within the planted row) and were thinned to a single seedling 12 months after planting. The aim of the double planting was to minimize the effects that variation in stocking may have on long-term growth measurements. A prolonged drought in the spring of 1995 resulted in extremely poor survival at site 3801, which was subsequently replanted the following winter.

Because our goal was to isolate the tillage effects on soil properties and seedling survival and growth, we applied weed control and fertilization to the control and the tilled plots. All trials were fertilized the first year after planting with 200 lb per ac (224 kg per ha) diammonium phosphate (DAP), which added 36 lb per ac N + 40 lb per ac P (40 kg per ha N + 45 kg per ha P) except trial 0101, which received 142 lb per ac DAP (160 kg per ha), which added 26 lb per ac N + 28 lb per ac P (29 kg per ha N + 31 kg per ha P). Competing vegetation was controlled during the first two growing seasons using repeated applications of herbicide at labeled rates. The number of herbicide applications, chemicals used, application rates, and application methods varied across study sites. The vegetation control achieved during the first two growing seasons, however, exceeded typical operational control levels at the time. Although the sites were qualitatively assessed to ensure that the standard of vegetation control was suficient to meet the goals of the trial, no quantitative assessments of vegetative cover were made at any of the sites.

After the first growing season, seedling survival was assessed. In the four trials that were double planted, survival of both seedlings was determined. If both seedlings survived, survival was 100 percent; if only one seedling survived, survival was 50 percent. Survival data were transformed before analysis using an arcsine transformation to normalize the data.

Table 1. Site and soil characteristics for each study site. The subsoil depth represents the depth of the transition to an argillic horizon (Bt). Soil texture was determined at a soil depth of 20 in (50 cm).

Study	Year trial established	Physiographic provence	County, State	Principal soil series	Drainage class[1]	Mineralogy	Depth to subsoil (cm)	Subsoil texture[2]
0101	1994	Piedmont	Laurens, SC	Cecil, Pacolet, and Appling	w	kaolinitic	19	scl and cl
0601	1997	Piedmont	Halifax, NC	Tatum	w	mixed	18	c
2801	1998	Upper Coastal Plain	Little River, AR	Smithton	w	siliceous	38	sl
3201	1996	Upper Coastal Plain	Santa Rosa, FL	Bama and Norfolk	w	siliceous	28	sl and scl
3801	1995	Piedmont	Saluda, SC	Appling	mw and w	kaolinitic	31	sc
4501	1998	Upper Coastal Plain	Wilcox, AL	Izagora	mw	siliceous	28	l and cl

[1] Drainage Class: mw = moderately well; p = poor; w = well.
[2] Texture: c = clay; l = loam; s = sand; si = silt.

Table 2. Pretillage soil texture, bulk density, total carbon, soil strength, and aeration porosity for surface (A) and subsurface (Bt) horizons on each study site.

Site	Horizon	Depth (cm)	Texture[1]	Bulk density (g per cm^3)	Soil strength[2] (MPa)	Aeration porosity (%)	Total carbon (g per kg)
0101	A	0–19	ls	1.54	1.5	16	9.6
	Bt		scl	1.52	5.5	8	5.0
0601	A	0–18	sl	1.44	1.2	14	12.6
	Bt		cl	1.45	3.1	9	4.4
2801	A	0–38	sl	1.60	1.4	5	6.1
	Bt		l	1.65	3.2	5	2.1
3201	A	0–28	ls	1.56	1.6	9	10.3
	Bt		scl	1.61	3.9	8	3.0
3801	A	0–31	sl	1.58	3.9	9	7.9
	Bt		cl	1.52	5.6	6	3.4
4501	A	0–28	sl	1.57	1.7	5	8.5
	Bt		l	1.60	2.7	3	2.3

[1] Texture: c = clay; l = loam; s = sand; si = silt.
[2] Soil strength was predicted for soil moisture at field capacity (0.03 MPa) using equations from da Silva and Kay (1997).

Total height and diameter at breast height (dbh) of surviving trees was measured in December or January after the second, fourth, and sixth years following planting (with the exception of site 3801, which was not measured during the fourth year). Individual tree volume was calculated using the equation for inside bark volume developed by Smalley and Bower (1968): inside bark volume (ft^3) = 0.002 by dbh (in^2) by height (ft). Summing individual tree volumes in each plot and scaling to per acre values based on the area of each plot determined volume per acre.

For each site, survival, cumulative height, diameter, and volume at age 6 were analyzed using paired sample t-tests in SAS (SAS Institute, Cary, NC). Trends in volume growth over time were determined using data from ages 2, 4, and 6 analyzed using repeated measures procedures in PROC MIXED (SAS Institute, Cary, NC) to determine whether the treatments affected tree growth rates during their first 6 years. A first-order autoregressive covariance structure was used in these analyses.

Results and Discussion

Differences in first-year survival between seedlings planted in plots tilled using the 3-in-1 combination plow and those planted in the nontilled control plots ranged from small and statistically insignificant at sites 0601, 2801, 3801, and 4501 to a significant ($p = 0.058$) increase of 14 percent at site 3210 (table 3). Because all the trials had good weed control and were fertilized to ensure adequate nutrition, the improved survival is most likely attributable to improved soil tilth. Improved soil physical properties following tillage can increase root growth and allow seedlings to more quickly explore deeper soil horizons, which allows them to access more soil water than seedlings in the nontilled plots (Campbell et al. 1974, Morris and Lowery 1988, Wheeler et al. 2002). This method reduces the likelihood of water stress during dry periods.

The results from this study, however, suggest that the effect of improved soil physical properties on seedling survival on these cutover sites is relatively small when good weed control is obtained using herbicides.

After 6 years, there were significant treatment effects at only two trial sites. Seedlings in trial 3210 were significantly greater in height, dbh, and volume in the tilled treatment compared with the control (table 3). At this site, volume of seedlings in the 3-in-1 combination plow treatment averaged 179 ft^3 per ac (12.6 m^3 per ha) more than in the control treatment. Seedlings in the tillage treatment at trial 0101 tended to have larger dbh than those in the control treatment (table 3). Seedling growth showed no significant differences among treatments at the other four locations.

Volume growth rate through time of seedlings planted in the 3-in-1 combination plow treatment was more than for those planted in the nontilled control treatment at three of the installations: 0101, 2801, and 3201 (figure 3). On site 3201, where the greatest response to tillage using the 3-in-1 combination plow occurred, the volume growth rate was 29.8 ft^3 per ac per yr (2.1 m^3 per ha per yr) more per year

Table 3. One-year mean survival, and six-year mean height, dbh, and volume for each treatment at each site. The p values are the results of paired t-tests between comparable replicates of nontilled and 3-in-1 combination plow treatments at each site. The analysis with the survival data used arcsine transformed means.

Sites	Number of repetitions	Survival (%)			Height ft (m)			dbh in (cm)			Volume ft^3 per ac (m^3 per ha)		
		Nontilled	3-in-1 plow	P value	Nontilled	3-in-1 plow	P value	Nontilled	3-in-1 plow	P value	Nontilled	3-in-1 plow	P value
0101	3	91	97	0.061	22.0 (6.7)	23.3 (7.1)	0.960	4.5 (11.5)	4.9 (12.5)	0.072	629 (44)	778 (54)	0.221
0601	4	75	85	0.637	14.4 (4.4)	14.4 (4.4)	0.997	3.0 (7.5)	2.9 (7.4)	0.291	154 (10)	157 (11)	0.795
2801	4	95	98	0.914	19.4 (5.9)	21.3 (6.5)	0.131	3.8 (9.6)	4.2 (10.7)	0.141	240 (16)	341 (24)	0.544
3201	4	82	96	0.058	23.3 (7.1)	26.3 (8.0)	0.032	4.1 (10.5)	4.5 (11.5)	0.041	410 (28)	589 (41)	0.035
3801	2	68	77	0.379	19.0 (5.8)	19.4 (5.9)	0.254	3.9 (9.8)	3.8 (9.7)	0.889	344 (24)	374 (26)	0.611
4501	3	95	96	0.915	30.2 (9.2)	30.5 (9.3)	0.361	5.1 (12.9)	5.2 (13.1)	0.153	1,106 (77)	1,158 (81)	0.531

than the untilled control. The growth response was much lower, however, on the other sites. Across all six trials, the average volume growth gain following tillage using the 3-in-1 combination plow was only 15.6 ft^3 per ac per yr (1.1 m^3 per ha per yr) relative to the control. This gain is relatively small compared with those reported for other silvicultural treatments applied in young loblolly pine plantations. For example, the average growth response during the 6 years after nitrogen and phosphorus fertilization was 62.4 ft^3 per ac per yr (4.4 m^3 per ha per yr) (NCSFNC 1997). The cost of this tillage operation is considerable, averaging $185 per ac ($457 per ha) in 2012 (Dooley and Barlow 2013). The growth responses we observed in these trials are unlikely to be large enough to pay for such an expensive treatment, particularly when the costs must be carried for 20 to 25 years until the end of the rotation.

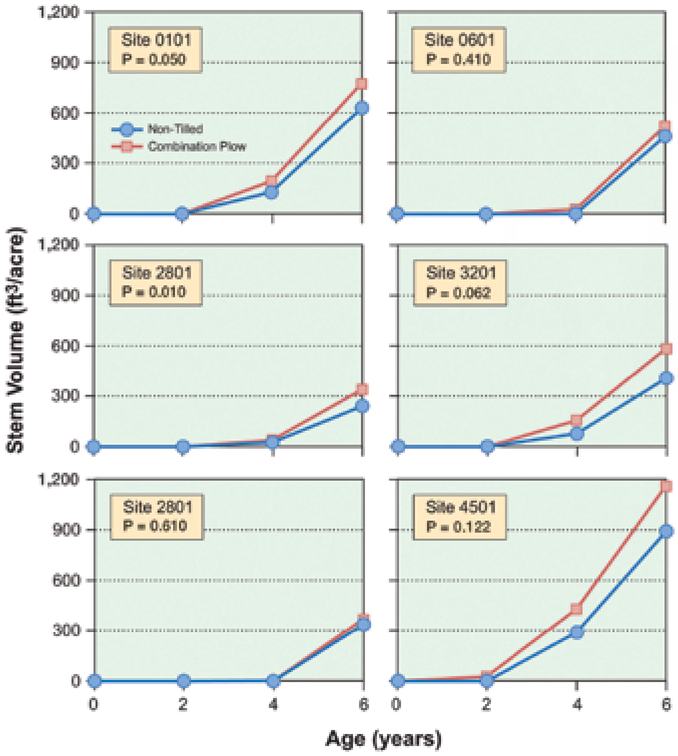

Figure 3. Cumulative volume at the different sites for the nontilled plots and the combination plow treatment. P-values on the individual graphs are the results of the repeated measures analysis for the Time by Treatment interaction.

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REFERENCES

Campbell, R.G.; Reicosky, D.C.; Doty, C.W. 1974. Physical properties and tillage of Paleudults in the Southeastern Coastal Plain. Journal of Soil and Water Conservation. 29: 220–224.

Carlson, C.A.; Fox, T.R.; Colbert, S.R.; Kelting, D.L.; Allen, H.L.; Albaugh, T.J. 2006. Growth and survival of Pinus taeda in response to surface and subsurface tillage in the Southeastern United States. Forest Ecology and Management. 234(1–3): 209–217.

da Silva, A.P.; Kay, B.D. 1997. Estimating the least limiting water range of soils from properties and management. Soil Science Society of America Journal. 61: 877–883.

Dooley, E.; Barlow, R. 2013. Special report. 2013 cost and cost trends for forestry practices in the South. Forest Landowner. 2011(July/August): 22–28.

Fox, T.R.; Jokela, E.J.; Allen, H.L. 2007. The development of pine plantation silviculture in the Southern United States. Journal of Forestry. 105(5): 337–347.

Gent, J.A.; Ballard, R.; Hassan, A.E.; Cassel, D.K. 1984. Impact of harvesting and site preparation on physical properties of Piedmont forest soils. Soil Science Society of America Journal. 48: 173–177.

Lowery, R.F.; Gjerstad, D.H. 1991. Chemical and mechanical site preparation. In Duryea, M.L.; Dougherty, P.M., eds. Forest regeneration manual. Boston: Kluwer Academic Publishers: 251–265.

Morris, L.A.; Lowery, R.F. 1988. Influence of site preparation on soil conditions affecting stand establishment and tree growth. Southern Journal of Applied Forestry. 2: 170–178.

North Carolina State Forest Nutrition Cooperative (NCSFNC). 1997. Response of young loblolly pine to nitrogen, phosphorus, and potassium fertilization. NCSFNC Research Report No. 38. Raleigh, NC: College of Forest Resources, North Carolina State University. 27 p.

Schilling, E.B.; Lockab, B.G. 2004. Biomass partitioning and root architecture responses in loblolly pine seedlings to tillage in Piedmont and Coastal Plain soils. Southern Journal of Applied Forestry. 28(2): 76–82.

Smalley, G.W.; Bower, D.R. 1968. Volume tables and point sampling factors for loblolly pine plantations on abundant fields in Tennessee, Alabama, and Georgia Highlands. Research Paper SO-32. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Wheeler, M.J.; Will, R.E.; Markewitz, D.; Jacobson, M.A.; Shirley, A.M. 2002. Early loblolly pine stand response to tillage on the Piedmont and Upper Coastal Plain of Georgia: mortality, stand uniformity, and second and third year growth. Southern Journal of Applied Forestry. 26(4): 181–189.