Establishment of White Oak Seedlings with Three Post-Plant Handling Methods on Deep-Tilled Minesoil during Reclamation[1]

Roger Kjelgren[2], Brenda Cleveland[3], and Mike Foutch[3]
Department of Plant and Soil Science
Southern Illinois University, Carbondale IL

Abstract

Three methods to improve first-year establishment of bare-root white oak on compacted minesoil during reclamation were investigated. We applied tree-shelter, hydrophilic-polymer, and nitrogen-fertilization treatments to seedlings planted on deep- and untilled soil. Predawn and midday water potential, and midday stomatal conductance (g_s) were measured in early, mid, and late season. Leaf area, trunk diameter growth, and survival were measured in early fall. Single-row deep tillage loosened the soil to 0.7 m (2.3 ft), but outward from the midrow the effect dissipated rapidly. Water stress increased in all treatments during an extended mid-summer dry period. Deep tillage resulted in higher initial g_s but differences in water stress between tillage treatments were not sustained during the dry period. Trees in shelters, however, were able to delay water stress longer than those in the other handling treatments. While there were no differences in trunk diameter growth among all treatments, trees on deep-tilled soil had greater leaf area and survival than those on untilled soil. Among handling treatments, only trees in shelters had leaf area and survival significantly greater than the control. Both deep tillage and shelters contributed to improved survival, and the greatest effect occurred with shelters on deep-tilled soil.

Index words: tree shelter, hydrophylic polymer, fertilization, water relations.

Species used in this study: white oak (*Quercus alba L.*).

Herbicides used in this study: Roundup® (Glyphosate), (N-(phosphonomethyl)glycine, ispropylamine salt); Oust® (sulfometuron-methyl), (methyl 2-[[[[(4,6-dimethyl-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoate).

Significance to the Nursery Industry

Deep tillage and tree shelters improved survival and growth of bare-root white oak during first-year establishment. Tree shelters were more effective in delaying the onset of water stress and also allowed greater leaf area, apparently through reduced animal depredation. Deep tillage of reclaimed minesoil would appear to improve initial tree establishment, particularly in dry years, and possibly provide an enlarged root zone to sustain continued growth. These results can benefit wholesale nurseries that sell volume quantities of liner stock to institutions engaged in large-scale revegetation efforts on compacted soil by providing appropriate recommendations for improving seedling establishment. Benefits from tree shelters in establishing bare-root liners can also be applied by field nurseries.

Introduction

Achieving acceptable survival and growth of tree seedlings during reclamation on surface-mined coal land has been difficult (1). Poor survival and growth has been attributed to compaction arising during reclamation from federally mandated replacement and grading to approximate original contours of stockpiled sub- and topsoil (2). Compaction imposes a chronic stress that limits survival and growth of trees (16). Water can be a critical limiting factor in compacted soils because loss of pore space reduces aeration and impedes drainage (5). Loss of pore space also lowers water holding capacity (7), and compaction limits rooting volume (3), which combined can lead to water stress (14). Bare-root seedlings are particularly vulnerable and have been difficult to establish on compacted minesoil (18).

Initial establishment is the most critical stage for successful reclamation using trees (1). Deep tillage has improved establishment of conifers (8) and survival of direct-seeded trees (12) on compacted minesoil, possibly by reducing water stress. It is, however, not readily available nor conclusively beneficial, and timing of tillage is important to achieve maximum effect. Several post-plant management methods may be equally effective in improving establishment and be more easily implemented. Hydrophilic polymers have been shown to improve water availability and reduce water stress (9) and can be added around the seedling roots at the time of planting. Tree shelters minimize water loss and animal damage, and have improved survival and growth in forest revegetation (17). Nitrogen fertilization has also been observed to improve tree growth during reclamation (15). Evidence is limiting, however, on the degree to which deep tillage affects establishment of bare-root seedlings in comparison to these other management options. We investigated the effect of deep tillage with three post-plant handling methods on seedling survival, growth, and water relations during first-year establishment on compacted minesoil.

Materials and Methods

The experiment was located on a hill created from the overburden taken from the initial cut of a dragline surface-mining operation in southwest Perry County, Illinois. The location was originally farmland, and the current minesoil classification is a Schuline silt loam (fine, loamy, mixed mesic Typic Udorthent). Reclamation began in 1987 with the cast overburden graded to a 2–5 percent slope, then approximately 1.3 m (4.3 ft) of stockpiled subsoil rooting me-

---

[1] Received for publication October 14, 1993; in revised form February 7, 1994.

[2] Assistant Professor. Present address: Department of Plants, Soils, & Biometeorology. Utah State University, Logan, UT 84322.

[3] Former graduate assistants.

dium (former C horizon) was replaced by bucket wheel and leveled. Finally, 0.20 to 0.50 m (8–20 in) of stockpiled topsoil was then replaced with scraper pans and a mixed grass-legume cover was seeded.

The experiment was laid out in a complete-block, split-plot factorial design replicated five times. Each main-plot treatment, deep- or no-tillage, was divided into randomly assigned sub-plots consisting of post-plant handling treatments. Each sub-plot consisted of a row 40 m (131 ft) in length with 19 trees planted on 2 m (6.6 ft) spacing, with 3 m (9.8 ft) spacing between rows. The deep tillage treatment was applied in September 1990 when soil water content was at a minimum. A single winged, fixed-hitch shank was used that reached to a maximum depth of 0.7 m (2.3 ft) within the planting row. Bare-root, white-oak (*Quercus alba*) seedlings, 0.15–0.30 m (0.5–1 ft) in height, were mechanically planted on April 3, 1991. Competing herbaceous vegetation was controlled in a 0.6 m (2 ft) wide strip stradling the tree row with non-selective pre- (Oust®) and post-emergent (Roundup®) herbicides. Between-row aisles were mowed twice during the season.

Handling treatments were applied after planting but prior to budbreak: nitrogen (N) fertilization, hydrophilic polymer, and tree shelters. We broadcast 1 gm (0.002 lb) of actual N, as sulfur-coated urea, around the base of each fertilized tree. This was based on an assumed rate of 9 gm (0.02 lb) N per 0.025 m (1 in) of trunk diameter. Hydrophilic polymer (Terrasorb Inc. Bradenton FL) was added at 150 gm (0.33 lb) per tree by pouring finely ground polymer crystals in an open wedge located 10 cm (4 in) away from each treatment tree, and then sealing the wedge. Tree shelters 1.2 m (4 ft) in height (Tubex Co., St. Paul, MN) were installed by inserting the base 0.025 m (1 in) into the soil and secured to a wood stake driven next to the tube.

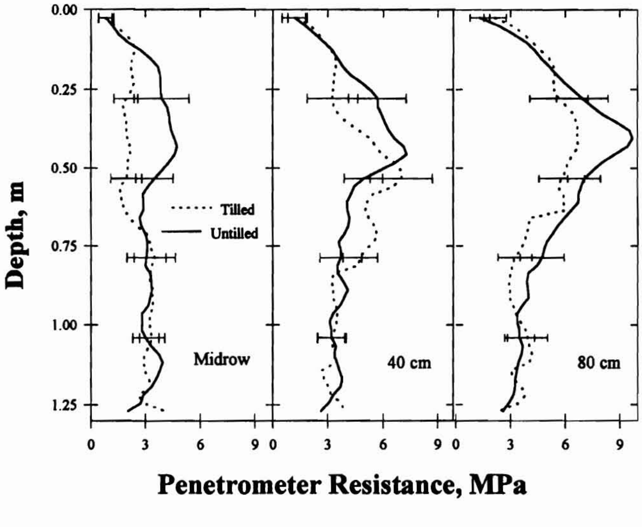

Fig. 1. Soil resistance (MPa) by depth in deep- and untilled minesoil midrow, and averaged for 0.4 and 0.8 m on either side. Error bars represent variances pooled in 0.25 m increments by depth.Table 1. Predawn water potential for white oak on deep (DT) and untilled (UT) minesoil. Means for handling treatments for each tillage treatment and overall within a column (n = 5) with a common letter are not significantly different at the 0.05 level using Duncan's Mean Separation. Differences indicated by asterisks between tillage-treatment averages for a particular handling treatment or for all handling treatments combined are significant at the 0.05 level.

Soil strength was measured in October 1991 to a depth of 1.5 m (5 ft) using a constant-velocity, auto-recording cone penetrometer (10). Soil penetration was measured in 0.025 m (1 in) increments in the middle, and 0.4 m (1.3 ft) and 0.8 m (2.6 ft) away on either side, of a randomly selected tree row within each subplot. Number of surviving seedlings in each experimental unit, based on the presence of either a green cambium or a viable bud, was determined after leaf drop in the fall. Leaves were collected from all live trees within a row prior to leaf drop, and total leaf area per row was measured with a leaf area meter (Model LI-3000 LI-COR, Lincoln, NE). Trunk diameter growth at 0.15 m (6 in) height was calculated as the difference between trunk diameter measured prior to budbreak and after leaf drop. Shoot elongation was not measured due to animal depredation.

Predawn and midday water potential (Ψ) were measured on three dates during the 1991 growing season with a pressure chamber (Model 3000 Soil Moisture Inc. Goleta, CA). Predawn Ψ, indicating plant-water-status in equilibrium with soil moisture, was measured on one leaf from a single representative tree from each subplot. The leaves were excised and placed in air-tight aluminum foil bags for storage until measurement, usually within two hours (13). Midday measurements were taken between 1300–1500 hrs when time-related changes in water relations were at a minimum following the same procedure. Data were taken only on the first three replicates to accommodate this time constraint. Stomatal conductance (g_s) was measured on three leaves from the same trees as midday Ψ with a steady-state porometer (Model LI-1600, LI-COR, Lincoln, NE).

Differences between tillage-treatment, and among handling-treatment, means for survival, growth, and water relations data were statistically analyzed according to the split-plot design. Duncan's multiple range was used for post-hoc comparison of means among handling treatments when the interaction term for the tillage and handling treatments were significant. Differences between tillage treatment means within each handling treatment were compared with *t*-tests. A 0.05 probability level was used for all significance tests. Penetrometer resistance was combined for similar distances away from the mid-row, and the mean, plus variance pooled in 0.25 m (0.8 ft) increments, were plotted against depth.

Results and Discussion

Tillage loosened the soil to approximately 0.7 m (2.3 ft) in the middle of the tree row (Fig. 1). Similar levels of resistance in both the deep- and untilled soil from 0–0.2 m (0–0.7 ft) depth showed that physical conditions in the topsoil layer were not different between tillage treatments. This corresponded to about the depth of penetration and soil loosening by the mechanical planter. Differences were more distinct beneath the topsoil layer. In the subsoil layer of the midrow, soil resistance remained at about 2 MPa in deep-tilled soil down to 0.7 m (2.3 ft). Root growth is generally not impeded below this level of soil resistance (19). Soil resistance increased to over 5 MPa in the untilled subsoil layer, reaching a maximum at 0.4 m (1.3 ft); this was probably the depth of maximum compaction by the machinery used for soil placement and grading. The tillage effect was detectable in the subsoil to 0.4 m (1.3 ft) on either side of the tree row but was superseded by variation among blocks at 0.8 m (2.6). These data, and a pH of 5.5 to 6.7 (data not

Table 1. **Predawn water potential for white oak on deep (DT) and untilled (UT) minesoil. Means for handling treatments for each tillage treatment and combined within a column (n = 5) with a common letter are not significantly different at the 0.05 level using Duncan's Mean Separation. Differences indicated by asterisks between tillage-treatments for a particular handling method or for all handling methods combined, are significant at the 0.05 level.**

	June 27			July 31			August 12		
	DT	UT	Tillage combined	DT	UT	Tillage combined	DT	UT	Tillage combined
Predawn Water Potential, MPa									
Handling combined	–0.25*	–0.41*		–1.02	–1.76		–0.96	–1.24	
Control	–0.22	–0.33	–0.27	–1.62	–1.22	–1.41	–0.99	–1.08	–1.03
Nitrogen	–0.24	–0.30	–0.27	–0.63*	–2.78*	–1.33	–0.71	–1.29	–0.95
Polymer	–0.26*	–0.36*	–0.30	–1.00	–1.20	–1.09	–0.92	–0.85	–0.89
Shelter	–0.28	–0.49	–0.37	–0.86	–1.33	–1.07	–1.35	–1.84	–1.55
Midday Water Potential, MPa									
Handling combined	–1.84	–2.23		–3.28	–3.53		–3.37	–3.67	
Control	–1.85	–2.46	–2.16	–3.58a	–3.47a	–3.52	–3.37	–3.79	–3.56
Nitrogen	–1.97	–2.17	–2.07	–3.54a	–4.04a	–3.79	–3.51	–3.68	–3.6
Polymer	–1.68	–2.27	–1.98	–3.18ab	–3.81a	–3.5	–3.41	–3.48	–3.44
Shelter	–1.60	–1.60	–1.60	–2.81b	–2.80b	–2.81	–3.19	–3.68	–3.40
Stomatal Conductance, mmol m^{-2} s^{-1}									
Handling combined	123*	85*		5	1		2	2	
Control	146ab	85	116	3	1	2b	2	3	3
Nitrogen	87bc	86	87	1	0	0b	3	2	2
Polymer	133ab	90	111	3	0	1b	1	2	2
Shelter	183a	77	131	31	6	14a	4	2	3

shown), were consistent with the observations of Bussler et al. (5) that compliance with current reclamation regulations results in soil chemistry generally acceptable for plant growth but undesirable physical conditions.

Tillage had less effect on delaying water-stress onset than did the handling treatments (Table 1). Initially (June 27), predawn Ψ for handling treatments combined was significantly less negative in the deep-tilled treatments, indicating less water stress. Seedling water stress increased through the season as predawn Ψ declined 3–8 fold in all treatments from June to July and August due to low rainfall. Two weeks prior to the June sampling 14 mm of rain fell, none fell during the two weeks before the July sampling, after which 10 mm fell prior to the August sampling. While trees on deep-tilled soil had generally less negative Ψ levels than those on untilled, July differences between tillage treatments were not significant due to variation among blocks, apart from the fertilized treatment. There were no detectable differences among handling treatments on any date.

Midday Ψ followed a similar pattern by also declining over the season in all treatments, indicating increasing water-stress. It was generally less negative in trees on deep-tilled soil than those on untilled soil, but again significant differences between tillage treatments were not detected on any date. Differences among handling treatments were detected in July. Trees in shelters had significantly less negative midday Ψ than any other treatment in both the deep- and untilled treatments. Lower internal water deficits suggested that shelters buffered the trees from ambient conditions and possibly lowered transpiration rates (4). By August, however, the effect of shelters was minimal as midday Ψ had reached levels similar to the other handling treatments.

Stomatal conductance responded to both tillage and shelters. Consistent with predawn Ψ, g_s was higher in the deep-tilled treatments initially, but was significant only for handling treatments combined. Conductance declined by July and August in all treatments as a result of water stress, and no significant differences between tillage treatments were detected. Shelters appeared to have delayed the onset of water stress more than deep tillage. In July, tree shelters with tillage treatments combined had significantly higher g_s than the other treatments. Higher g_s but lower midday Ψ for this same date again indicated that shelters had a buffering effect on water loss. Protected conditions in shelters apparently decoupled g_s from the bulk air (11), effectively decreasing boundary-layer conductance and thereby reducing transpiration.

Leaf area and survival followed the relative pattern of deep-tillage and tree-shelter effects on water relations (Table 2). Trunk diameter was not different either among handling or between tillage treatments, while leaf area was larger and survival higher for all handling treatments on deep-tilled soil. Except for survival in the hydrophilic polymer treatment, however, differences between tillage treatments were significant only when handling treatments were combined. Among handling treatments, shelters significantly increased both leaf area and survival. Leaf area of trees in shelters was significantly larger on both deep- and untilled soil. This was likely due to the shelters protecting foliage from depredation (17), since there was clear evidence of browsing by small animals on those trees not in shelters. White-oak survival was higher in shelters, but only when tillage treatments were combined was significance detected.

Overall, deep tillage and shelters were both superior to the other treatments in improving bare-root seedling estab-

Table 2. **Leaf area, trunk caliper growth, and survival of white oak on deep (DT) and untilled (UT) minesoil. Means for handling treatments for each tillage treatment and combined within a column with a common letter are not significantly different at the 0.05 level using Duncan's Mean Separation. Differences indicated by asterisks between tillage-treatments for a particular handling method or for all handling methods combined, are significant at the 0.05 level.**

	Leaf area, cm^2			Caliper, mm			Survival, %		
	DT	UT	Tillage combined	DT	NT	Tillage combined	DT	NT	Tillage combined
Handling combined	718*	24*		0.84	0.69		73*	52*	
Control	994b	251ab	691	0.76	0.92	0.84	72	60	66ab
Polymer	782b	120ab	489	0.78	0.69	0.73	68	47	57bc
Nitrogen	812b	119ab	518	0.96	0.76	0.86	81*	58*	69ab
Shelter	4645a	2121a	3281	0.96	0.71	0.84	83	71	77a

lishment and growth. While fertilization had no detectable effect, nitrogen could become limiting after establishment, regardless of tillage, since stockpiled soil is typically low in organic matter and mineralization potential and high in denitrifying organisms (6). The addition of hydrophilic polymer did not benefit water relations, and the slight negative effect on growth may have been due to soil compression around the roots while creating a wedge to apply the polymer. It is possible that roots did not grow enough to exploit water held in the polymer and that benefits may appear in later years.

Tillage and shelters combined improved survival and growth over each treatment separately. They both would appear to moderate water stress in a somewhat complementary manner. Tillage likely increased water supply by creating a larger volume of loosened soil, and shelters appeared to reduce evaporative demand while physically protecting foliage from damage. Tillage had more of an effect on growth than on water relations, however, possibly due to our low-resolution sampling that did not detect changes in water relations between tillage treatments. It is also possible that these seedlings did not grow enough to fully exploit the increased moisture in the enlarged root zone and that the effect on growth could have been the result of lower impedence at the margins of root growth. Improved water availability with deep tillage could become more important several years after establishment as demands for soil resources increases the demand for rooting volume, particularly during dry years.

Combining the two methods in a practical situation would be of questionable cost effectiveness, however. Deep tillage probably has a lower per-tree cost than shelters, but it may have little effect on establishment in wetter years when water deficiency is less likely, and it requires specialized equipment that may not always be available. Shelters would seem to be of more certain benefit from year-to-year because they buffer foliage from water loss and depredation. Since they would likely have a higher per-tree cost, the particular planting situation would have to warrant the expenditure.

Literature Cited

1. Andersen, C., B. Bussler, W. Chaney, P. Pope, W. Byrnes. 1989. Concurrent establishment of groundcover and hardwood trees on reclaimed mined land and unmined reference sites. For. Ecol. and Manag.. 28:81–99.

2. Ashby, W. 1983. Is good for corn good for trees? p. 15–18. *In*: Proc. Post Mining Productivity with Trees. Carbondale, IL.

3. Barnhisel, R. 1988. Corrections of physical limitations to reclamation. p.191–211. *In*: Vol. II. L R. Hossner (ed.) Reclamation of Surface-Mined Lands. CRC Press, Boca Raton, FL.

4. Burger, D., P. Svihra, and R. Harris. 1992. Treeshelter use in producing container-grown trees. Hortscience 27:30–32.

5. Bussler, B., W. Byrnes, P. Pope, and W. Chaney. 1984. Properties of minesoil reclaimed for forest land use. Soil Sci. Soc. Am. J. 48:178–184.

6. Chong, S, E. Varsa, B. Klubek, J. Steiner, F. Olsen, D. Stucky, X Hu, and L. Bledsoe. 1990. Surface-mined land reclaimed by the cross-pit bucket wheel excavation system. p. 6.1–6.14 *In*: Proc. First Midwestern Regional Reclamation Conference, National Mined Land Reclamation Center, Southern Illinois University, IL.

7. Dollhopf, D. and R. Postle. 1988. Physical parameters that influence successful minesoil reclamation. p. 81–104. *In*: Vol. I. L. R. Hossner (ed.) Reclamation of Surface-mined Lands. CRC Press, Boca Raton, FL.

8. Foil, R., and C. Ralston. 1967. The establishment of Loblolly pine seedlings on compacted soils. Soil Sci. Soc. Amer. Proc. 31:565–568.

9. Henderson, J., and D. Hensley. 1986. Efficacy of a hydrophilic gel as a transplant aid. Hortscience 21:991–992.

10. Hooks, C., and I. Jansen. 1986. Recording cone penetrometer development in reclamation research. Soil Sci. Soc Am J. 50:10–12.

11. Jarvis, P. and K. McNaughton. 1986. Stomatal control of transpiration: Scaling up from leaf to region. Adv. Ecol. Res. 15:1–49.

12. Josiah, S., and G. Philo. 1985. Minesoil construction and ripping affects long term black walnut growth. p. 209–225 *In*: Proc. Better Reclamation with Trees Conf. Southern Illinois University, Carbondale.

13. Karlic, H. and H. Richter. 1979. Storage of detached leaves and twigs without changes in water potential. New Phytol. 83:379–384.

14. Nambiar, K., and R. Sands. 1991. Effects of compaction and simulated root channels in the subsoil on root development, water uptake and growth of radiata pine. Tree Physiol. 10:297–306.

15. Plass, W. and J. Powell. 1988. Trees and shrubs. p.175–200. *In*: Vol. II. Hossner, L.R. (ed.). Reclamation of Surface-Mined Lands. CRC Press, Boca Raton, FL.

16. Philo, G., C. Kolar, W. Ashby. 1982. Effects of ripping on minesoil compaction and black walnut establishment. p. 551–557. *In*: Proc. Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, KY.

17. Potter, M. 1988. Treeshelters improve survival and increase early growth rates. J. For. 86:39–41.

18. Rietveld, W. 1989. Transplanting stress in bareroot conifer seedlings: Its development and progression to establishment. North. J. Appl. For. 6:99–107.

19. Taylor, H. and E. Burnett. 1964. Influence of soil strength on the root-growth habits of plants. Soil Sci. 98:174–180.