Reforestation / Reclamation

RENEWING A FOREST ECOSYSTEM IRRIGATED WITH TREATED WASTEWATER

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Abstract—Treated wastewater is being irrigated on declining upland forest ecosystems in central Pennsylvania. To renew the forest community, four clearcut treatments were administered to determine the effects of season of harvest and residue on the resulting vegetation. Two years after the clearcut treatments, forb, grass and vine plants covered > 90 percent of the ground surface. Densities of naturally occurring seedling- and sapling-sized stems of shrub and tree species were insufficient for a fully stocked forest stand. Two years after clearcutting, the average densities of shrub and tree seedling-sized stems were 3,056 and 1,319 stems per hectare, respectively. The average densities of shrub and tree sapling-sized stems were 1,209 and 846 stems per hectare, respectively. There were some significant differences in densities among clearcut treatments, however, there was no consistently better treatment after two years.

Artificial regeneration was used to augment natural regeneration. Green ash (*Fraxinus pennsylvanica* Marsh.), quaking aspen (*Populus tremuloides* Michx.), northern red oak (*Quercus rubra* L.) and pin oak (*Q. palustris* Muenchh.) were planted to evaluate their potential survival and growth in the wastewater conditions. At the end of the two growing seasons, overall average survival was 98 percent for green ash and 88 percent for quaking aspen. These two species responded to the additional nutrients and water, and after two growing seasons had overall average total heights of 156 centimeters and 222 centimeters, respectively. Neither northern red oak nor pin oak survived or grew as well as the green ash and quaking aspen. After two growing seasons, the oaks were smaller than when originally planted. Green ash and quaking aspen showed excellent potential to respond to the wastewater irrigation conditions and can be used to renew the forest stands.

INTRODUCTION

Disposal of sewage effluent has become a major problem for many municipalities due to escalating human populations and stricter regulatory controls on disposal methods. Nutrient-rich wastewater from sewage treatment plants is usually discharged into nearby rivers or lakes, often leading to serious environmental problems through eutrophication of aquatic systems. Disposal of secondary treated sewage effluent on land has several potential advantages, including reducing stream pollution and recharging ground water reserves (Sopper and Kardos 1973).

Experiments conducted in forested communities have shown that spray irrigation with chlorinated sewage effluent caused changes in the structure and species composition of vegetation. Increased rates of tree growth and plant biomass, altered species composition of ground-level vegetation, and decreased production and survival of native shrub and tree species have all been reported (Brister and Schultz 1981, Epstein and Sawhill 1977, Sopper and Kardos 1973). It is believed that these changes are due to the addition of nutrients and water to the soil and damage caused by ice loading during winter.

In 1983, The Pennsylvania State University engaged in a full-scale spray-irrigation system for municipal wastewater on 209 hectares of farm and forest land owned by the Pennsylvania Game Commission. The forest land contains ecosystems that are important landscape features to a comprehensive land application system. These include important noise and visual screens for adjacent landowners, all-season wastewater receptors, nutrient accumulators, and habitats for wildlife. The irrigation schedule of 5 centimeters of wastewater per week for 52 weeks, since 1983 had reduced the upland forest overstory density by 33 percent. Many of the remaining 75 to 125 year old trees were in a poor state of health (Larrick and Bowersox 1999). The irrigated forest generally had upper soil nitrate-nitrogen levels > 10 milligrams/liter, which was above the U.S. Public Health potable water standards. This illustrated that the irrigated forest was not renovating the wastewater and needed to be renewed (Storm 1995).

In 1992, an exploratory study with 0.4-hectare units was designed to examine the potential to replace the deteriorating overstory with young vegetation. This study investigated how the amount of irrigation and seasonal timing of application could affect species composition of a forest community being regenerated by clearcutting. This study indicated that woody vegetation was markedly reduced in clearcuts irrigated with 5 centimeters of treated wastewater for 52 weeks per year; forb and vine plants dominated these areas. Clearcuts irrigated with 5 centimeters of wastewater for 26 weeks (during the growing season only) contained more shrub and tree stems, but were still dominated by forb and vine plants. The soil nitrate-nitrogen in the young clearcuts was < 10 milligrams/liter, demonstrating that the young vegetation can reduce the amount of nitrogen in the soil percolate (Storm 1995).

In 1995, a research study was implemented to determine how the wastewater irrigated forest stands could be

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renewed. Three, 8-hectare clearcuts were installed to examine the effect of four harvest treatments on the resulting plant community which was being irrigated weekly with 5 centimeters of wastewater from May through October. This paper presents the first and second year responses of the ground cover plants, naturally occurring understory shrubs and trees, and artificially regenerated tree species to four clearcut harvest treatments.

PROCEDURES

The study area was located in central Pennsylvania, 2 kilometers north of State College. The gently rolling terrain is in the Ridge and Valley region (Lull 1968) on lands managed by the Pennsylvania Game Commission. The Pennsylvania State University operates a wastewater irrigation system over the study area. Treated wastewater is distributed by aboveground sprinkler-heads that rotate 360 degrees for even distribution. The soil was Morrison sandy loam (Ultric, Hapludalf; fine, loamy, mixed, mesic). Site quality was about average, and if occupied by even-aged mixed oak stands, the site index would be about 20 meters at 50 years.

Plant response to season of cutting and residue were studied in an area clearcut in 1995-96. There were three, 8-hectare replications of four, 2-hectare treatment units for a total area of 24 hectares. Each replication contained four harvest treatments which were: Summer/Remove with complete tree removal (cut in August 1995); Summer/Leave with no tree removal (cut in September 1995); Winter/Remove with complete tree removal (cut in January 1996); and Winter/Leave with no tree removal (cut in February 1996). Removal treatments were done by feller-buncher and grapple skidder combination. Leave treatments were done by directional felling with chainsaws, and all residue was lopped to within 1 meter of the ground. All shrubs and trees > 2 centimeters d.b.h. were severed at < 30 centimeters above ground in all treatments. There was greater disturbance in the Remove treatments than in the Leave treatments caused by the dragging of felled stems across the seedbed. Between the Summer/Remove and Winter/Remove treatments, the latter had less impact because the presence of snow on the ground protected the seedbed.

Inventories of ground cover, and abundance of shrub and tree seedling-sized stems (1 to 150 centimeters in height) and sapling-sized stems, including stump sprouts (151 centimeters in height and 1 to 10 centimeters in diameter), were conducted in 1995 to determine the understory composition prior to harvest treatment. During the first (1996) and second (1997) growing seasons after harvest treatment, these inventories were continued on randomly located permanent plots. There were 144 pairs of fenced and unfenced 2-square meter plots (12 pairs per treatment per replication) for the ground cover and seedling inventories, and 96, 100-square meter plots (8 per treatment per replication) for the sapling inventories. Ground cover was separated into three categories: forbs (including broadleaf herbaceous plants), grass, and vine plants (both woody and non-woody). Annual estimations of cover, to the nearest 5 percent were made in August. Densities of seedling-sized stems by height and species, and densities of sapling-sized stems by d.b.h and species, were measured at the end of each growing season.

Seedlings of four hardwood tree species were planted in spring of 1996 to determine their potential to survive and grow in the wastewater irrigated clearcuts. The species planted as bareroot seedlings were green ash, quaking aspen, northern red oak and pin oak. Plantings were in four pairs of 18-square meter fenced and unfenced plots per treatment unit. A 2 percent solution of glyphosate was sprayed prior to planting to reduce competition. Hand-weeding was done during the rest of the growing season. The fence was 1.3-meters tall and used to deter deer browsing of the planted seedlings. A total of 1,152 bareroot seedlings of each species were planted at a 1-tree/0.5 square meter density. The initial height of each of the seedlings was recorded shortly after planting. Survival and height were measured at the end of the first and second growing seasons. Evidence of browsing was recorded at the end of each growing season, and also in April of 1997 to determine damage caused by white-tailed deer (*Odocoileus virginianus*).

From 1983 to 1995, the study area received 5 centimeters of wastewater irrigation for 52 weeks each year. In 1996 and 1997, these areas were irrigated with 5 centimeters of wastewater weekly for 26 weeks (May 1 to October 31). Irrigation during the winter months was avoided so that regeneration was not damaged by ice loading. The nutrient concentration of the applied effluent can vary considerably depending on the volume of incoming wastewater to the treatment facility, as well as the procedures used to analyze it. Table 1 is a coarse estimate of some of the nutrients added to the study site.

A completely random experimental design was used. Analysis of variance ($\alpha = 0.05$) was used to test replication, treatment and fence (where appropriate)on: ground cover, density of naturally occurring seedlings and saplings, and survival and growth of planted seedlings. Percentage data was arcsine transformed prior to analysis. Tukey's HSD mean separation procedure ($\alpha = 0.05$) was used to determine significant differences between treatments.

RESULTS AND DISCUSSION

Naturally Occurring Plants

Ground cover—Prior to overstory removal, forb, grass and vine coverages were not significantly different among harvest treatments (Table 2). Overall, forb (22 percent), grass (1 percent), and vine (8 percent) plants covered about 30 percent of the ground surface prior to clearcutting.

In 1996, the average coverage of both forb and vine plants was significantly different among treatments (Table 2). The Winter/Leave treatment had the least amount of forb coverage (60 percent) and the most vine coverage (24 percent) of all the treatments. Grass coverage did not differ significantly among treatments in 1996, and the overall average coverage was 2 percent (Table 2).

Table 1—Amount of nitrite-N, nitrate-N, phosphorus, calcium and magnesium annually added in the wastewater from 1983 through 1995[a] and 1996-1997[b]. Values were based on treatment plant output concentration values, which varied considerably, depending on analytical method, supply to and procedures at the treatment plant

Period	Nitrite-N	Nitrate-N	Phosphorus	Calcium	Magnesium
	----------	----------	*Kg/ha*	----------	----------
1983-1995	79	69	95	1,188	581
1996	1	32	53	647	330
1997	1	37	79	568	277

[a] Based on 52 weeks of 5 cm of wastewater per week
[b] Based on 26 weeks of 5 cm of wastewater per week

Table 2—Average[a] forb, grass and vine coverage for the harvest treatments, by species group, for before (1995), one year after (1996) and two years (1997) after clearcut

Year and harvest treatment	Forb	Grass	Vine
	-----------	Cover pct	-----------
1995			
Summer/remove	24a	0a	10a
Summer/leave	23a	0a	7a
Winter/remove	20a	0a	6a
Winter/leave	20a	2a	8a
Overall	22C	1A	8C
1996			
Summer/remove	75a	2a	9b
Summer/leave	77a	4a	14ab
Winter/remove	72a	1a	12ab
Winter/leave	60b	0a	24a
Overall	71A	2A	15B
1997			
Summer/remove	66a	3a	26a
Summer/leave	67a	5a	22a
Winter/remove	63a	1a	30a
Winter/leave	63a	1a	30a
Overall	65B	3A	27A

[a] Values within each species group by year with the same lower case letter were not significantly different at the 0.05 level. Overall treatment values among years within each species group with the same upper case letter were not significantly different at the 0.05 level.

In 1997, there were no significant differences among harvest treatments as to average forb, grass and vine coverage values (Table 2). Overall, the average coverage of forb (65 percent), vine (27 percent), and grass (2 percent) plants amounted to a total of 94 percent of ground cover during the second growing season.

Approximately twelve forb species were found in the irrigated clearcut areas. Garlic mustard (*Alliaria petiolata* (Bieb.) Cavara & Grande) and spotted touch-me-not (*Impatiens capensis*) comprised most of the forb cover in the clearcuts. These two species tend to dominate any area when present. There were five vine species found in the clearcuts. Bittersweet nightshade (*Solanum dulcamara* L.) was the most abundant vine species followed by Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch).

There were distinctly different post-treatment seedbed conditions among the four harvest treatments, which we expected would have influenced the different forb and vine communities. It was our observation that the Winter/Leave and Summer/Leave treatments had more vine coverage than the Summer/Remove and Winter/Remove treatments, however this was not reflected in the data. Sampling intensity may not have been adequate to detect significant differences in the ground coverage among treatments.

Averaged over all harvest treatments, there were significant, temporal differences in forb and vine coverages (Table 2). The coverage values were all significantly different after the clearcut treatments. Forb coverage increased from 22 percent before the clearcut to 71 percent in the first year after the clearcut and then declined to 65 percent in the second year. This suggests that forb coverage may have reached a maximum level during the first growing season after the clearcuts and was beginning to decline. Vine coverage was significantly different among all inventories. Coverage increased with time in all of the treatments and was becoming a major component of the plant community.

Seedling-sized stems—Inventories conducted prior to clearcutting indicated that there was an overall average density of 365 shrubs and 538 tree seedling-sized stems per hectare (Table 3). There were no significant differences among treatments in the density of shrub and tree seedling-sized stems per hectare prior to overstory removal.

Table 3—Average[a] density of shrub and tree species seedling-sized stems for the harvest treatments, before (1995), one year after (1996) and two years (1997) after clearcut

Species and harvest treatment	1995	1996	1997
	------------ Stems/*ha* ------------		
Shrubs			
Summer/remove	139a	555a	1,181b
Summer/leave	972a	1,181a	5,208a
Winter/remove	69a	349a	3,472ab
Winter/leave	278a	138a	2,361b
Overall avg.	365B	556B	3,056A
Trees			
Summer/remove	69a	0a	208b
Summer/leave	1,806a	833a	2,639a
Winter/remove	69a	139a	2,083a
Winter/leave	208a	139a	347ab
Overall avg.	538B	278B	1,319A

[a] Harvest treatment values by species group within each year with the same lower case letter were not significantly different at the 0.05 level. Overall treatment values among years within each species group with the same upper case letter were not significantly different at the 0.05 level.

One year after clearcutting (1996), the overall density of shrub seedling-sized stems increased from 365 to 556 stems per hectare (Table 3). There was no significant difference among treatments in the density of shrub seedling-sized stems after overstory removal. The overall average density of tree seedling-sized stems decreased from 538 to 278 stems per hectare one year after overstory removal. There were no significant differences among treatments.

Two years after the clearcut treatments (1997), the overall average density of shrub seedling-sized stems increased to 3,056 from 556 stems per hectare, and there were significant differences among treatments (Table 3). The density of tree seedling-sized stems also increased in the second year after treatment. Overall, the average density of tree seedling-sized stems was 1,319 per hectare and there were significant differences among treatments. The Summer/Leave and Winter/Remove treatments had the greatest densities of both shrub and tree seedling-sized stems. Both of these treatments had two replications that bordered existing forest stands and as such may have recruited more individuals.

Over all the harvest treatments, the density of seedling-sized stems of both shrub and tree species were significantly different among inventories. The average density of shrub seedling-sized stems in 1997 (3,056 stems/hectares) was significantly different than in 1996 (556 stems/hectares) and prior to clearcutting (365 stems/hectares). Tree seedling-sized stem average density was also significantly different in 1997 (1,319 stems/hectares) than in 1996 (278 stems/hectares) and prior to the clearcut treatments (538 stems/hectares) (Table 3). Except for the Winter/Remove treatment, there were no marked changes in the densities of shrub and tree seedling-sized stems among the three inventories (Table 3). The Winter/Remove treatment had a substantial increase in both shrub and tree seedling-sized stems in 1997 compared to 1995 and 1996. With this one exception and the overall low densities, there was no strong evidence that any of the four treatments really made a difference in the success of securing a desirable stocked stand.

Sapling-sized stems—Prior to overstory removal, the overall average density of shrub sapling-sized stems was 1,318 per hectare, and there were significant differences among treatments (Table 4). The overall average density of tree sapling-sized stems was 392 stems per hectare and there were no significant differences among treatments.

One year after the clearcut treatments (1996), the overall average density of shrub sapling-sized stems decreased from 1,318 to 309 stems per hectare (Table 4). There were significant differences among the four treatments. The Winter/Remove treatment had a significantly different density of sapling-sized stems (1,004 stems/hectares) than the Summer/Leave, Summer/Remove, and Winter/Leave treatments (8, 191, and 33 stems/hectares, respectively). The overall average tree sapling-sized density also decreased one year after the clearcut treatments from 392

Table 4—Average[a] density of shrub and tree species sapling-sized stems for the harvest treatments, before (1995), one year after (1996) and two years (1997) after clearcut

Species and harvest treatment	1995	1996	1997
	------------ Stems/*ha* ------------		
Shrubs			
Summer/remove	458b	191b	321b
Summer/leave	758b	8b	1,058ab
Winter/remove	2,608a	1,004a	933ab
Winter/leave	1,446ab	33b	2,525a
Overall avg.	1,318A	309B	1,209A
Trees			
Summer/remove	361a	13a	549a
Summer/leave	294a	8a	975a
Winter/remove	349a	8a	935a
Winter/leave	575a	29a	950a
Overall avg.	392B	15C	846A

[a] Harvest treatment values by species group within each year with the same lower case letter were not significantly different at the 0.05 level. Overall treatment values among years within each species group with the same upper case letter were not significantly different at the 0.05 level.

to 15 stems per hectare and there were no significant differences among treatments.

In 1997, two years after clearcutting the average density of shrub sapling-sized stems increased to 1,209 from 309 stems per hectare and there were significant differences among the four treatments (Table 4). The Winter/Leave treatment had a significantly different average density of shrub sapling-sized stems (2,525 stems/hectares) than the Summer/Remove treatment (347 stems/hectares). The Summer/Leave and Winter/Remove treatments were not significantly different from the other two treatments with 1,770 and 933 shrub sapling-sized stems per hectare, respectively. The overall average density of tree sapling-sized stems two years after clearcutting was 846 per hectare, which was more than twice the amount of stems found prior to the clearcut treatments.

There were significant differences among years in the densities of shrub and tree sapling-sized stems (Table 4). The overall average density of shrub sapling-sized stems in 1997 (1,209 stems/hectares) was not significantly different from the average density in 1995, prior to clearcutting (1,318 stems/hectares). The density of shrub sapling-sized stems in 1996 (309 stems/hectares) was significantly different from both the 1995 and 1996 densities. The average density of tree sapling-sized stems in 1997 (846 stems/hectares) was significantly different than in 1996 (15 stems/hectares)and prior to overstory removal (392 stems/hectares).

The density of tree and shrub sapling-sized stems initially decreased after the clearcut because all sapling-sized stems were intentionally removed during harvest. Both the densities of shrub and tree sapling-sized stems increased during the second year of the study, but were still insufficient for stocking the forest stands.

Forb and vine plants prior to clearcutting covered about 30 percent of the ground layer. By the end of two growing seasons, the coverage had increased to nearly 90 percent. Forb plants were frequently > 1 meter tall and vines completely entangled seedlings. The degree to which these plants were influencing the survival and growth of the shrub and tree reproduction was not measured in this study. Over all harvest treatments, there were 1,337 seedling-sized and 846 sapling-sized tree stems per hectare two years after clearcutting. The reproduction contained a greater proportion of black cherry (*Prunus serotina* Ehrh.), red maple (*Acer rubrum* L.) and white ash (*Fraxinus americana* L.), and fewer oak (*Quercus* spp.) and hickory (*Carya* spp.) stems than were present in the pre-treatment overstory. Stump sprouting accounted for very few individuals that occurred in the natural regeneration of the stand. The greater diversity indicated that there was a potential for other tree species to become established and grow in the wastewater conditions, but at lower densities than desirable using either the Marquis and others (1992) or Bowersox and others (1998) standards. The Marquis and others standard requires a minimum of 3,330 seedling-sized or 1,334 sapling-sized stems per hectare to have adequate stocking on 70 percent of the area. The standard that Bowersox and others are using in a model being tested in mixed-oak stands of central Pennsylvania requires a minimum of 25,950 tree seedling-sized or 2,595 tree sapling-sized stems per hectare to recommend clearcutting. Based on these two years of data, it is clear that clearcutting the present stands, without augmentation and possibly vegetation control, will not produce a fully stocked forest stand.

Artificial Regeneration

Green ash, quaking aspen, northern red oak, and pin oak were selected to enhance natural regeneration because of their potential value to wildlife and their capability to respond to the additional water and nutrients. Green ash is a fast-growing species that grows best on fertile, moist, well-drained soils (Kennedy 1990). Quaking aspen, another fast-growing species grows best on well-drained, loamy soils that are high in organic matter, calcium, magnesium, potassium, and nitrogen (Perala 1990). Northern red oak is moderate- to fast-growing and achieves its best growth on deep, well-drained loam to silty-clay loam soils (Sanders 1990). Pin oak is found on poorly-drained alluvial floodplains and river bottoms, and it is also fast-growing (McQuilkin 1990).

The first-year survival of the four planted tree species was excellent (Table 5). Northern red oak had the lowest overall average survival of 91 percent, while green ash had 100 percent survival. Green ash and quaking aspen did not have significantly different survival among the four harvest treatments. There were significant differences among treatments for the survival of both oak species.

Height growth and total height for the first growing season varied among species, and within species among treatments (Table 5). Green ash planted seedlings had good height growth during the first growing season. Overall, green ash seedlings grew 45 centimeters and were 107 centimeters tall at the end of the first growing season (Table 5). Both the Summer/Leave and Summer/Remove treatments had an average height growth of 47 centimeters and were significantly different from the Winter/Leave (41 centimeters) and the Winter/Remove (43 centimeters) treatments. The overall average total height (107 centimeters) of the green ash seedlings was not significantly different among treatments.

Quaking aspen had the greatest average height growth and average total height of all four species planted. Overall, quaking aspen planted seedlings grew 105 centimeters and were 134 centimeters tall after the first growing season. The Summer/Remove treatment had the greatest average height growth (131 centimeters) and total height (158 centimeters) and was significantly different from the other three treatments.

Northern red oak and pin oak did not attain the height growth in the first growing season that the quaking aspen and the green ash did. Height growth was significantly different among treatments for both oak species (Table 5).

Table 5—Average[a] first and second year survival, height growth and total height for planted green ash, quaking aspen, northern red oak and pin oak seedlings, by harvesting treatment

	First year			Second year		
Species	Survival	Height growth	Total height	Survival	Height growth	Total height
	Pct	--------*Cm* --------		Pct	--------*Cm* -------	
Green ash						
Summer/leave	100a	47a	109a	99a	44b	165a
Summer/remove	100a	47a	110a	99a	60a	152ab
Winter/leave	100a	41b	106a	99a	56a	144b
Winter/remove	100a	43b	104a	97a	45b	159ab
Overall avg.	100	45	107	98	51	156
Quaking aspen						
Summer/leave	100a	100b	125b	89ab	104b	279a
Summer/remove	98a	131a	158a	92a	128a	215b
Winter/leave	100a	99b	133b	87b	98b	175c
Winter/remove	99a	88b	121b	85b	80c	218b
Overall avg.	99	105	134	88	104	222
Northern red oak						
Summer/leave	93a	13ab	47a	53a	1a	29a
Summer/remove	93a	15a	48a	56a	1a	28a
Winter/leave	87b	12b	50a	41a	-1a	21a
Winter/remove	92a	11b	48a	42a	1a	20a
Overall avg.	91	13	48	48	1	25
Pin oak						
Summer/leave	100a	10a	32a	85a	0a	24b
Summer/remove	99a	10a	29b	71b	2a	28a
Winter/leave	98a	9b	27c	77ab	1a	24b
Winter/remove	96b	8b	28bc	79a	1a	22b
Overall avg.	98	9	29	78	1	25

[a] There were 288 bare-root seedlings per species planted in each of the four harvest treatments. Harvest treatment values within each species and year with the same letter were not significantly different at the 0.05 level.

Northern red oak did not significantly differ in average total height among treatments and the overall average total height was 48 centimeters. Pin oak significantly differed in total height among treatments, but the amount of growth was very low in all treatments, averaging 9 centimeters (Table 5).

At the end of the first growing season, all four species had better height growth (Table 5) in the Summer harvest treatments than in the Winter harvest treatments. There did not seem to be any consistent patterns in height growth between residue treatments (Remove vs. Leave) or in total height among season and residue treatments.

After the second growing season the green ash and quaking aspen continued to have high survival, but there was a dramatic decrease in the survival of the two oak species (Table 5). Overall, green ash had 98 percent survival and quaking aspen had 88 percent survival. Northern red oak had the greatest decline in survival from 91 percent to 48 percent (Table 5). Pin oak survival also declined, from 98 percent to 78 percent at the end of the second growing season.

Green ash and quaking aspen continued to respond with vigorous height growth during the second growing season. Over all harvest treatments, green ash grew an average of 51 centimeters (Table 5). Green ash had significantly different height growth among treatments with the Summer/Remove (60 centimeters) and Winter/Leave (56 centimeters) treatments being significantly different from the Summer/Leave (44 centimeters) and Winter/Remove (45 centimeters) treatments. The overall average total height was 156 centimeters and there were significant differences among treatments.

In the second growing season, quaking aspen had the greatest height growth and obtained the tallest total height of all four species. Overall, quaking aspen grew an average of 104 centimeters and averaged 222 centimeters in height (Table 5). Summer/Leave (104 centimeters) and Winter/Leave (98 centimeters) treatments were significantly different from the Winter/Remove (80 centimeters) treatment, but not from each other. All three of these treatments were significantly different from the Summer/Remove treatment, which had the greatest average height growth of 128 centimeters.

Second-year average height growth and average total height for the two oak species were lower than the averages obtained in the first year of the study (Table 5). Overall average height growth of northern red oak and pin oak was 1 centimeter each, and the overall total height of both species averaged 25 centimeters. Overall, both the northern red oak and pin oak failed to demonstrate acceptable growth in these wastewater conditions. Neither of the oaks would be able to surpass the canopy of the competing forb, grass and vine plants.

At the end of two growing seasons, it was determined that the quaking aspen and green ash seedlings had acceptable height growth and could be used to regenerate the irrigated clearcuts. There does not seem to be any consistent evidence to suggest which treatment may be the best for artificially regenerating the irrigated forest.

White-tailed deer browsing in the first growing and dormant season was less than 10 percent of all planted seedlings. In the spring of the second growing season, before and after bud break, browsing became a frequent occurrence in the fenced and unfenced plots. The number and average two-year total height of the browsed and not-browsed planted seedlings are presented in Table 6. There was a significant difference in the species-specific heights between the seedlings that were not browsed and those that were browsed. The average height of the non-browsed quaking aspen seedlings was 257 centimeters. This was more than 11 times greater than the average height of quaking aspen seedlings that were browsed (22 centimeters). Green ash, northern red oak, and pin oak seedlings that were not browsed had average heights 1.5, 5, and 3 times greater than seedlings that were browsed. The number of browsed green ash and quaking aspen stems were lower than the number of browsed northern red oak and pin oak stems. We believe that the oaks were more frequently browsed mainly because their height made them more accessible to the white-tailed deer.

Based on the silvics of each of the four species, all had the potential for responding favorably to the additional water and nutrients that are being added by the wastewater effluent. However, only the green ash and quaking aspen responded as expected to the effluent treatment applied to the clearcut areas. It is possible that the northern red oak species could not tolerate the additional 5 centimeters of water per week during the growing season. Pin oak, however, should have been able to adjust to the additional water. One explanation for why the oaks did not respond was that they could not adapt to the soil chemistry found at the site. Competition for light was controlled in the first growing season by herbicides and hand-weeding of the plots. Light competition did not seem to be the reason why the two oak species did not exhibit similar growth to the quaking aspen and the green ash during the first growing season. During the second growing season, however, it was possible that the green ash and quaking aspen may have contributed to the decline of the two oak species. By the end of the first growing season, the quaking aspen and the green ash started to overtop the oaks. Another explanation may be that the oaks were more frequently browsed because they were preferred by white-tailed deer, or their heights made them more accessible for browsing.

Table 6—Number and average[a] two-year old total height of green ash, quaking aspen, northern red oak and pin oak seedlings browsed and not browsed during the second growing season

	Browsed		Not-browsed	
Species	Number of seedlings	2-year total height	Number of seedlings	2-year total height
		Cm		*Cm*
Green ash	78	93b	1,057	161a
Quaking aspen	31	22b	979	257a
Northern red oak	203	11b	353	55a
Pin oak	172	11b	723	33a

[a] Total height values within each species with the same letter were not significantly different at the 0.05 level.

SUMMARY AND CONCLUSIONS

Pennsylvania State University has been studying over-land irrigation of treated wastewater as an alternative to discharging into local streams since the 1970's. In the summer of 1995 and winter of 1996 three replications, of four clearcut treatments were administered to assess the potential for the naturally occurring seedling-sized and sapling-sized shrubs and trees to develop young, well-stocked forest stands. An initial inventory of tree and shrub species densities found that natural regeneration was insufficient and that artificial regeneration would be necessary. The treatments units were used to determine the effects of season of harvest (Summer or Winter) and residue (Remove or Leave) on the ground cover, naturally occurring shrubs and trees and artificial regeneration. Two years after the clearcut treatments, forb and vine plants averaged > 90 percent of the existing ground cover. Naturally occurring seedling- and sapling-sized stems of shrub and tree species were insufficient for stocking a healthy forested ecosystem. Two years after clearcutting, the average densities of shrub and tree seedling-sized stems were 3,056 and 1,337 stems per hectare, respectively. The average densities of shrub and tree sapling-sized stems were 1,209 and 846 stems per hectare, respectively. There were some significant differences in densities among treatments, however, there was no consistently better treatment two years after clearcutting. Overall, the densities of tree seedling- and sapling-sized stems ere insufficient to stock a forest stand capable of renovating the wastewater.

Green ash, quaking aspen, northern red oak and pin oak were planted to evaluate their potential survival and growth in the wastewater conditions. At the end of two growing seasons, overall average survival for green ash was 98 percent and quaking aspen was 88 percent. These two species also had overall average total heights of 156 centimeters and 222 centimeters, respectively, after two growing seasons, demonstrating their ability to respond to the additional nutrients and water. The two oak species did not survive and grow as well as the green ash and quaking aspen. After two growing seasons, the oaks were smaller than when originally planted. We believe that green ash and quaking aspen can be planted to regenerate the irrigated clearcuts, augmenting the existing natural regeneration in renewing the forest stands.

Future research studies will focus on the effects of forbs and vines on survival and growth of planted seedlings and securing natural regeneration before removing the overstory.

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NATIVE HIGH VALUE TREE RECLAMATION ON SURFACE MINED SPOILS IN EASTERN KENTUCKY

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Abstract—Grading standards on reclaimed coal mines as outlined in PL 95-87, the Surface Mining Control and Reclamation Act of 1977, have resulted in spoil compaction that severely limits tree root penetration. This leads to high tree seedling mortality. A field study was established on surface mined lands in eastern Kentucky to study the effects of two levels of compaction (no compaction and compacted) and two soil amendments (bark mulch and barn straw mulch) on three native high value tree species: white ash (*Fraxinus americana*), yellow-poplar (*Liriodendron tulipifera*), and northern red oak (*Quercus rubra*). Bark mulch seemed to have little effect on seedling vigor and survivorship and the barn straw seemed to lower both vigor and survivorship. Bulk densities for each compaction level were significantly different. Results are based on one year of data, in the future we hope to answer the question, will the uncompacted plots result in higher vigor and survivorship than the compacted plots, and that is our hypothesis.

INTRODUCTION

Coal mining has disturbed over 2.4 million ha in the United States since 1930 and the majority of that land was originally forested in Appalachia (Zeleznik and Skousen 1996). Often the best post mining land use is to return the lands to forests as quickly as possible. There is much interest in reclaiming mined lands with high value trees, especially if economical methods can be found. Reclamation costs could be significantly reduced if a method is developed to successfully establish trees and grasses (Larson and Vimmerstedt 1990).

In order to achieve productive forests on post mined lands, reclamation techniques that ensure good tree survivability and growth must be adopted (Campbell 1997). One of the key problems in establishing a productive forest on previously surfaced mined lands is excessive compaction, which leads to high tree seedling mortality. Chaney et al. (1995) believe that the initial condition of mined sites reconstructed under specifications of PL 95-87 result in a growth media that is less than optimal for high-value species of hardwood trees.

Reclamation research in the midwest has shown that pre-federal law mining sites resulted in some of the most productive areas in the region for the growth of tree seedlings (Ashby et al., 1978). A study by Burger and Torbert (1992) has shown that when mine spoil is loosely dumped without grading and planted with various species of trees, survival is higher than that on graded mine spoil. The problem of soil compaction has been approached in two ways: (1) prevent or minimize occurrence of the problem and (2) ameliorate the problem once it has happened (Sweigard, 1990). The former is preferable to the later because it conserves resources.

The two objectives of this study were to 1) investigate the effects of two levels of compaction on seedling survival of three native high value tree species, and 2) investigate the influence of two soil amendments on seedling survival of three native high value tree species. This paper reports first-year results and serves as baseline data for an ongoing study.

METHODS AND MATERIALS

Study Area

The study was conducted on a surface mine in eastern Perry County, Kentucky (37° 24' N, 83° 8' W). This mine is located in Kentucky's eastern coalfield in the Cumberland Plateau physiographic region. Climate is temperate humid continental with average annual precipitation of 117 cm, and an average monthly precipitation of 10 cm, which ranges from 6-12 cm. Average temperature is 13°, with a mean daily maximum and minimum of 31° and 18° in July and 8° and -4° in January (Hill 1976). The mine is within the Hazard Coal Reserve District as delineated by the U.S. Geological survey (Huddle et al. 1963).

Plot Construction

Six enclosed 1 ha plots, approximately 70 m wide and 155 m long, were constructed (Figure 1). Two of the plots (#7 and #8) were constructed in time for the 1996 planting season. Due to construction delays the remaining four plots were not ready until the 1997 planting season. Bulldozers were used to create the borders of the plots, which were required for a hydrologic study, earth moving equipment was then used to loose dump the spoil material in consecutive piles until the entire plot was filled. Three of the plots (#2,#3,#4) were left in the loose condition and represented the no compaction treatment. The other three plots (#7,#8,#9) were driven over repeatedly with a bulldozer and represented the compacted treatment, these compacted plots were constructed to industry compaction levels. When reestablishing forests in this region it is important to ensure adequate ground cover for erosion

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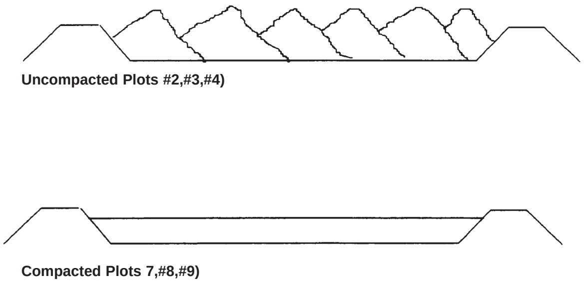

Figure 1—Cross-sectional diagram of plots. Plots are 70 m wide and 155 m long, borders of plots are 2-3 m high.

control; however if inappropriate herbaceous species are chosen, tree seedling survival will be reduced due to excessive competition. All plots were seeded with a slow establishing non-aggressive mixture of grasses and legumes. The grass and legume mixture consisted of annual rye (*Secale cereale*), perennial rye (*Lolium perenne*), orchard grass (*Dactylis glomerata*), birdsfoot trefoil (*Lotus corniculatus*), and Appalow lespedeza (*Serecia lespedeza*, var. Appalow) at the following rates of application 33.61 kg/ha for the annual rye and 5.61 kg/ha for each of the other species. Bark mulch was applied to two plots (#3,#8) at the rate of 125 ton/ha. Barn straw mulch was applied to two plots (#4,#7) at the rate of 125 ton/ha. The remaining plots (#2,#9) received no soil amendments.

Tree Species Selection

Tree species selection for our project was based on species that are native to the area, had documented performance in land reclamation, and a potential commercial value. White ash was chosen because it is a high value native tree species that has shown high survivability on surfaced mined lands (Zeleznik and Skousen 1996, Medvick 1969). Yellow-poplar was chosen because it is native to the area, very fast growing, and there is a rapidly growing market for this species. Northern red oak was chosen because it is a native species that has a high value.

Planting and Measuring of Tree Seedlings

Twenty-one subplots were established inside each of the plots. These subplots were 20 m x 20 m and one corner was permanently marked with rebar and metal tags identifying subplot number and species planted within the subplot. Each of the three species were randomly allotted to three subplots within each plot. The remaining twelve subplots in each plot were allotted to four other tree species not included in this study. Tree seedlings (1-0) were purchased from the Kentucky Division of Forestry's tree nursery in Morgan County, Kentucky. Tree seedlings were planted on a 1.8 m x 1.8 m spacing, yielding 121 trees per subplot. Two of the plots (#7,#8) were planted in the spring of 1996 and the remaining plots were planted in the spring of 1997. All tree seedlings were planted by professional tree planters. Annual measurements were made from the end of July through mid August. Total height of each tree was recorded to the nearest cm. In addition to total height, each tree was assigned a vigor class. Vigor classes were developed by the authors and consisted of five classes: 0-tree was dead, 1-tree was nearly dead, 2-intermediate/ stressed, 3-vigorous with one or two signs of stress, and 4-vigorous with no signs of stress. Signs of stress included chlorotic, withered, or misshapen foliage. Tree survival percentages were calculated by dividing the number of live tree seedlings measured in each plot by the number of trees originally planted in the plots. In addition to survivorship percentages, vigor rankings were characterized by the mode and mean of each plot.

Bulk Density

Bulk density is defined as the mass of a unit volume of soil (Brady 1990). There is a direct relation between bulk density and compaction level of the mine spoil. Bulk density was measured by a technique developed by Muller and Hamilton (1992). This technique consists of excavating a hole (approx. 1000 cm^3) in the mine spoil and carefully saving and weighing all material. The hole is then filled with expanding polyurethane foam, which can be obtained from most home improvement or building stores, cardboard is then secured on top of the hole to ensure that the foam fills all crevices in the hole. Curing of the foam takes 8 hrs, and after curing the foam is removed from the hole. Loose debris is then washed from the foam, and any foam that was not actually in the hole is removed. Spoil material was sieved using a 2mm sieve, weights of the sieved spoil material and the spoil material that would not pass through the 2mm sieve were recorded. This reveals the rock fragment content of the spoil material. Volume of the hole is then determined by displacing water with the foam. Seven subplots were randomly selected within each plot and sampled for their bulk density. To test for significant differences among compaction levels, a general linear model procedure with least significant difference t-tests of the SAS System (1996) was used.

Spoil Analysis

Characterization of the spoil materials chemical properties were obtained through spoil analysis. A composite sample was taken from five systematic sub-samples on each subplot. Care was taken to ensure that no soil amendments were included in the spoil analysis. Samples were submitted for analysis of ten parameters, which included organic matter, phosphorus, potassium, calcium, magnesium, pH, nitrate nitrogen, soluble salts, water holding capacity , and total nitrogen. There were a total of nine composite samples from each plot; results of spoil analysis were averaged for each plot.

RESULTS AND DISCUSSION

Because tree seedlings age varied, analysis was limited to reporting percentages and averages. Northern red oak preformed well on all plots (Table 1) except for plot #8 which was compacted and had barn straw added, this plot is also one year older. White ash preformed equally well on the uncompacted and compacted spoils; however yellow-poplar did better on the plots that were one year old as compared to the two year old plots. Mortality was highest on plots #7 and #8, where the seedlings were 1 year older than in the other plots. The big question is, how will the

Table 1—Tree survival on surface mined lands in eastern Kentucky, treated with two levels of compaction and two soil amendments

Plot	White ash	Yellow-poplar	Northern red oak
	Pct survival		
Measured in 1st growing season only			
2 Uncompacted/no mulch	89	90	93
3 Uncompacted/bark mulch	92	95	100
4 Uncompacted/barn straw	99	94	97
9 Compacted/no mulch	95	98	100
Measured in 2nd growing season only			
7 Compacted/barn straw	82	15	52
8 Compacted/bark mulch	97	41	96

one year old tree seedlings do next year, and will the compacted plots look similar to the uncompacted plots?

Compaction levels as characterized by bulk densities were significantly different at p=.05 (Table 2). Overall bulk density was 1.4 Mg/m^3 on the uncompacted spoils and 2.3 Mg/m^3 on the compacted spoils. Bulk density within the uncompacted plots was not different at the p=.05 level of significance, within the compacted level. Plots #7 and #8 were not different from each other. Rock fragment content ranged from 50.3 percent to 54.5 percent on the uncompacted plots and from 55.9 percent to 71.1 percent on the compacted plots (Table 3).

Nine composite samples were submitted for analysis of spoil chemical properties of each plot. Composite samples results were then averaged for the entire plot. Table 4 reports the average spoil characteristics of each plot.

Table 2—Bulk density (Mg/m^3) values on uncompacted and compacted plots on surface mined lands in eastern Kentucky

Plot	Bulk density
	*Mg/m^3**
Uncompacted	
2	1.5^{a}
3	1.3^{a}
4	1.4^{a}
Overall mean**	1.4^{1}
Compacted	
7	2.1^{a}
8	2.0^{a}
9	2.7^{b}
Overall mean**	2.3^{2}

*Bulk density values within a compaction level followed by the same letter are not significantly different at P=.05.
**Overall means for a compaction level followed by the same number are not significantly different at P=.05.

Plot #7 had the lowest mean vigor (1.18) of all the plots; however it is evident that vigor was lowest on the 2 year old seedlings as compared to the 1 year old seedlings. White ash preformed better on the one year old plot (Table 5). Yellow-poplar performed much better on the one year old plots than on the two year old plots (Table 6). The same pattern held true for northern red oak (Table 7) with performance better on the one year old plots as compared to the two year old plots. Overall vigor of the tree seedlings was highest on the one year old plots (Table 8).

Plots that were treated with soil amendments had lower overall vigor for all species than those plots left untreated. Plots treated with bark mulch fared better than those treated with the barn straw mulch. The barn straw mulch plots seem to support a much hardier ground cover than the bark mulch plots. This could have caused increased competition on the tree seedlings from the ground cover species.

Table 3—Average rock fragment content of spoil material on surface mined lands in eastern Kentucky

	Avg. weight of spoil material		
Plot	<2mm	>2mm	Average rock fragment
	g		*Pct*
2	852.92	864.22	50.3
3	1194	1431.3	54.5
4	1088	1267.4	53.8
7	890.09	1884.64	67.9
8	655.3	1613	71.1
9	707.92	898.85	55.9

Table 4—Average spoil characteristics of plots on surface mined lands in eastern Kentucky

	Plot					
	Uncompacted			Compacted		
Parameter	2	3	4	7	8	9
Organic matter (%)	1.8	2.0	3.2	4.0	4.7	2.8
Phosphorus (ppm)	0.0	0.0	0.0	0.3	0.3	0.3
Potassium (ppm)	4	6	13	14	11	11
Calcium (ppm)	56	46	79	48	60	80
Magnesium (ppm)	23	19	30	25	26	48
pH	5.9	5.2	5.8	6.9	7.5	6.9
Nitrate nitrogen (ppm)	25	4	7	11	35	38
Soluble salts (mmhos/cm)	0.4	0.4	0.6	0.4	0.5	0.7
Water holding capacity(%)	9.8	9.5	10.6	13.6	13.8	12.7
Total nitrogen (lb/acre)	624	653	1166	2034	1574	1107

Table 5—Vigor of white ash seedlings planted on surface mined lands in eastern Kentucky

Plot	N	Mode	Mean
Measured in 1st growing season only			
2 Uncompacted/no mulch	323	2	2.39
3 Uncompacted/bark mulch	333	2	2.24
4 Uncompacted/barn straw	375	2	2.24
9 Compacted/no mulch	345	3	2.49
Measured in 2nd growing season only			
7 Compacted/barn straw	364	2	1.69
8 Compacted/bark mulch	357	2	2.09

Note: vigor consisted of five classes: 0-dead, 1-nearly dead, 2-intermediate/stressed, 3-vigorous, slight stress present, 4-vigorous with no signs of stress.

Table 6—Vigor of yellow-poplar seedlings planted on surface mined lands in eastern Kentucky

Plot	N	Mode	Mean
Measured in 1st growing season only			
2 Uncompacted/no mulch	326	2	2.24
3 Uncompacted/bark mulch	346	2	2.14
4 Uncompacted/barn straw	340	2	2.13
9 Compacted/no mulch	355	2	2.25
Measured in 2nd growing season only			
7 Compacted/barn straw	363	0	0.32
8 Compacted/bark mulch	363	2	1.38

Note: vigor consisted of five classes: 0-dead, 1-nearly dead, 2-intermediate/stressed, 3-vigorous, slight stress present, 4-vigorous with no signs of stress.

CONCLUSION

This study reports first year data on establishment of native high-value tree seedlings on surface mined lands in eastern Kentucky. Current law requires mine operators to grade the surface to the approximate original contour which results in the soil being compacted to the point where seedling survival is severely hindered. Due to the fact that tree seedlings age varied we are unable to compare the compacted plots and uncompacted plots treated with soil amendments, and the two plots that had no soil amendments (compacted & uncompacted) had similar vigor and survivorship. The real question is will, once data has been collected for several years, the uncompacted plots result in higher vigor and survivorship than the compacted plots, and that is our hypothesis. If forestry is the post mining land use then bond release does not occur until five years after the last reclamation activity. Bark mulch seemed to have little effect on seedling vigor and survivorship and the barn straw seemed to lower both vigor and survivorship. In the future we hope to demonstrate that seedling survival will be least successful on compacted plots suggesting that a viable alternative to current reclamation practices exists; avoiding compaction by

Table 7—Vigor of northern red oak seedlings planted on surface mined lands in eastern Kentucky

Plot	N	Mode	Mean
Measured in 1st growing season only			
2 Uncompacted/no mulch	338	2	2.32
3 Uncompacted/bark mulch	363	2	2.23
4 Uncompacted/barn straw	353	2	2.22
9 Compacted/no mulch	363	2	2.08
Measured in 2nd growing season only			
7 Compacted/barn straw	363	0	1.05
8 Compacted/bark mulch	362	2	1.93

Note: vigor consisted of five classes: 0-dead, 1-nearly dead, 2-intermediate/stressed, 3-vigorous, slight stress present, 4-vigorous with no signs of stress.

Table 8—Vigor of white ash, yellow-poplar, and northern red oak tree seedlings planted on surface mined lands in eastern Kentucky

Plot	N	Mode	Mean
Measured in 1st growing season only			
2 Uncompacted/no mulch	987	2	2.32
3 Uncompacted/bark mulch	1042	2	2.20
4 Uncompacted/barn straw	1068	2	2.20
9 Compacted/no mulch	1063	2	2.27
Measured in 2nd growing season only			
7 Compacted/barn straw	1090	0	1.18
8 Compacted/bark mulch	1082	2	1.80

Note: vigor consisted of five classes: 0-dead, 1-nearly dead, 2-intermediate/stressed, 3-vigorous, slight stress present, 4-vigorous with no signs of stress.

minimizing grading. This will result in reclamation that is not only cheaper but will allow quicker establishment of productive forest lands. A limitation of this type of reclamation is that it requires relatively flat land, and while appropriate for mountaintop removal is of limited use on contour mines.

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GROWTH OF WHITE AND RED OAK SEEDLINGS AND SEED ON MINED UNGRADED CAST OVERBURDEN

W. Clark Ashby[1]

Abstract—Tree seedlings and/or seed of white oak (*Quercus alba* L.) and red oak (*Q. rubra* L.) were planted spring and fall from 1978 to 1982 on ungraded cast overburden (also termed spoil banks) in southern Illinois. Each planting season there were 50 seedlings, or seed spots, of each species per row in replicated plots. Some seasons no seedlings or seed were available for planting. The 20 plots had 1800 white oak and 1700 red oak planting spots total. The oak seedling and seed rows were randomly assigned with other species in a plot so that nearest neighbor tree rows differed from plot to plot. Soil bulk density averaged 1.3 grams per cubic centimeter, pH 7.5, and plant nutrients were low by agricultural standards. The ground cover was old-field weeds that were sprayed with herbicide in later planting years.

Trees in each row were counted 3 years after planting to determine establishment, that varied widely. In 1993-1994 all trees were measured for height and diameter breast height (DBH). Ages then ranged from 11 to 16 years. Survival after establishment was generally good, somewhat greater for red than white oak, for spring- than fall-planted trees of each species, and for trees planted as seedlings rather than seed. Heights of older spring-planted seedlings averaged more than 6 meters with DBHs, not here reported, more than 8 centimeters. Red oak tended to be taller than white oak. DBHs were more variable. Heights and DBHs of trees planted as seedlings tended to be greater than those planted as seed. Variations in survival and growth were not clearly attributable to quality of planting stock, use of herbicides, or differences in randomized nearest-row neighbors. Holding white oak seedlings in a cold room from spring over summer for fall planting gave reduced survival and equivalent growth.

INTRODUCTION

White and northern red oak are major components of forests in Illinois and other midwestern states (Burns and Honkala 1990). The natural importance of white oak is greater on mid to upper slopes, and of northern red, here called red, oak is greater in ravines and on lower slopes, related to aspect. These two high-quality species seem logical choices to use in reforestation of minesoils in the lower midwest. In turn, their growth on a rooting medium that does not occur naturally in the local climate can add to understanding of their ecological life requirements.

Within the past 50 years thousands of hectares in the midwest have been surface mined for coal and planted to millions of trees. In a pre-law period roughly from 1930 to 1960 in Illinois, 8.7 million hardwoods and 7.2 million conifers were voluntarily planted by coal companies and coal associations in cooperation with the Illinois Department of Conservation, the USDA Forest Service, and a few universities (Ashby and others 1978). Although scant records exist of the performance of these plantings other than the Forest Service and university research plots, overall tree performance was considered to be good to excellent, with failures of non-adapted species planted on isolated acidic areas.

A quarter million of the 8.7 million hardwoods in Illinois were white or bur (*Q. macrocarpa* Michx.) oak, and half a million were red or black (*Q. velutina* Lam.) oak. A 50-year-old white oak stand growing on ungraded cast overburden in southern Illinois had excellent survival, height of 26±3 meters, and a DBH of 23±1 centimeters (Ashby 1996). A near-by stand of red (intermixed with *Q. shumardii Buckley*) oak 55 years old also had excellent survival, average height of 33±3 meters, and DBH of 35±1 centimeters.

Many experienced reclamation, and an increasing number of regulatory, personnel have been concerned that trees planted in the 20 years since passage of a federal 1977 reclamation law have not survived and grown well compared to those planted pre-law (Ashby 1991). Another problem is that species with high 5-year survival rates selected for bond release commonly are not ecologically or economically desirable for long-term forestry plantings.

Viewing tree planting on post-law minesoils as a lost cause has unfortunately become a common misconception. State and federal regulatory authorities are now recognizing the need for re-evaluating out-dated regulations, with increased interest in successful reforestation. Even the well-documented effects of soil compaction from mandatory grading after mining (Josiah 1986) need not detract from the utility of studies of tree growth on minesoils. The adverse ecological and economic consequences of grading to parking-lot standards have been demonstrated. Mined lands can be reclaimed with minimal compaction using new grading methods and understanding. A great opportunity for restoring mined lands to productive forestry should not be neglected.

My research group in 1978 set up studies to document carefully the survival and growth of 25 tree species planted on ungraded cast overburden, including many of the hardwood species grown earlier. This paper reports

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performance of white and red oak, planted as seedlings, and as seed, if available. Plots replicated once were established each spring and fall from 1978 to 1982. Several survival counts and growth measurements were taken in later years. The goals of this paper include:

1. To evaluate and compare relative performance of white and red oak planted as seedlings or seed during fall and spring for 5 years on ungraded cast overburden.
2. To compare tree performance when planted fall or spring.
3. To compare tree performance when planted as seedlings or seed.
4. To evaluate white oak performance using other kinds of growing stock.

METHODS AND MATERIALS

My study area is on the Sahara Coal Company, Inc. surface mine No. 6 just west of Harrisburg in southeastern Illinois. Annual temperature averages 13 degrees Centigrade, with July 25 degrees and January 0 degrees Centigrade, and annual precipitation 1100 millimeters. Figure 1 has the growing season precipitation from April through September 1978 to 1984, years of tree establishment and early growth. Monthly temperatures for this period were tabulated and are not here listed.

Rooting Medium

The predominant regional pre-mining soil was Hosmer silt loam, Typic Fragiudalfs Alfisols (Miles and Weiss 1978). A geological column taken on the permit area in 1981 prior to mining was described in an unpublished report by W.C. Hood. He reported 4 meters of unconsolidated material overlying numerous intermixed layers of sandy shale (9 meters total), limestone (3 meters), and sandstone (1 meter) above a 1.5 meter-thick seam of No. 6 coal. The rooting medium of the spoil banks cast by a Marion 5761 power shovel was thus a mixture of soil fines and coarse fragments from shattered rock layers above the coal. The slopes of the bank ridges trending southeast-northwest ranged from 21 to 34 degrees and averaged 29 degrees. The ridges were spaced from 8 to 30 meters apart with an average distance of 20 meters. Bank heights ranged from 3 to 10 meters with an average height of 6 meters. Flooded areas between the banks were not found.

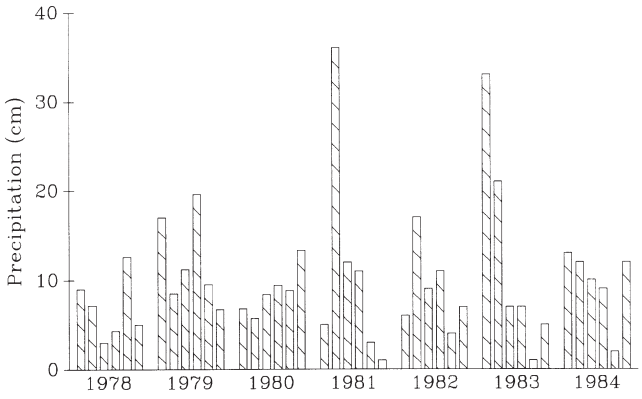

Figure 1—Growing-season (April-September) monthly precipitation from 1978 to 1984 recorded at Harrisburg, IL.

The bulk density of the cast overburden corrected for rock fragments ranged from 1.22-1.35 grams per cubic centimeter and the percent coarse fragments larger than 2 millimeters from 38-52 percent. Stones of varying sizes exposed on the surface functioned as an erosion pavement and provided numerous niches or micro-habitats for plant establishment and growth. Numerous excavations of cast overburden in later years showed deep rooting to 4 meters by various species with extensive branching of root systems. Roots also penetrated shale and sandstone fragments as they broke apart when exposed to near-surface weathering agents. The minesoil likely had a more favorable moisture regime for growth of deep-rooted plants than the fine-textured, fragipan native soils.

The post-mining rooting medium based on soil fines was classified as a silty clay loam to clay loam, probably related to the well-developed B horizon of the pre-mining fragiudalfs and to rapid weathering of the predominant shales of the overburden in the years between mining and tree planting. The rooting medium was mildly alkaline (pH 7.5) with average Bray-1 phosphorus 5 parts per million, Bray-2 phosphorus 24 parts per million, potassium 154 parts per million, magnesium 175 parts per million, and calcium 2313 parts per million (Josiah 1986). Variations among the individual measurements of these properties on the total 14-hectare plot area likely came from differential mixing of overburden materials in the mining process. The ground cover at planting ranged from sparse goldenrod (*Solidago L.* spp.) or broomsedge (*Andropogon virginicus* L.) and other old-field invaders to relatively dense patches of trumpet creeper (*Campsis radicans* (L.) Seemann.) or Japanese honeysuckle (*Lonicera japonica* Thunb.).

Planting Stock and Plot Layout

All seedlings were graded in the laboratory by basal caliper and the smallest ones rejected. Depending on stock quality and numbers available, the largest seedlings and those with carrot-type roots were also rejected. Numbers of lateral roots were not counted. Roots were trimmed to fit in a planting hole without distortion. Representative-sized seedlings for each row were bundled, 52 each, with roots packed in moist sphagnum moss in a plastic bag tied off around the lower stems. Acorns when collected were floated in water for approximately an hour and those undamaged that sank were similarly placed in moist sphagnum moss as recommended by Bonner (1993). Seedlings and seed were stored in a 5 degrees Centigrade cold room until planted.

Seedlings were planted with planting bars (dibbles). Seed was planted with a mattock, three acorns in a hole three times their diameter in depth. Each planting spot was marked with a color-coded pot label that aided in following a row for early survival counts on rough terrain and occasional thick vegetation.

Each replicated tree plot of this study had 20 randomly-assigned, single-species rows that included rows of white and red oak. Thus a red oak seedling row in one randomized plot was planted between a row of walnut (*Juglans nigra* L.) and of pin oak (*Q. palustris* Muenchh.), and in the paired plot was planted between a row of baldcypress (*Taxodium distichum* (L). Rich.) and of red oak from seed. An oak row was planted all to seedlings or all to acorns. Each row had 50 planting spots with 2.5 meters spacing between trees and rows. The replicated plots had 100 of each available oak species/planting stock planted each season. The rows ran primarily up and down across the banks rather than along the length of a bank.

White oak—The sum of the areas of the rows of white oak seedlings or seed spots planted both spring and fall from 1978 to 1982 was 1.12 hectares with 1800 trees. Quality of white oak nursery stock as received each year was rated as good to excellent except for root and stem damage noted for the 1980 seedlings planted fall 1980 and spring 1981. Limitations to growth of these seedlings were not evident in the 1993 measurements. Seedlings were donated from the Illinois Union County state tree nursery 100 kilometers southwest of the study site, except for fall 1981. The only seedlings planted fall 1981 were donated from the Licking, MO state nursery 200 kilometers further west. The Missouri seedlings were planted again for comparison with Illinois seedlings spring 1982. In other comparisons white oak seedlings were held in cold storage over a summer each for planting in fall 1979, and in fall 1980. Roots of the seedlings held over were dipped in a 1 percent Captan solution before placing in cold storage.

White oak seed was planted only in the fall each year. We were not successful in holding over a sufficient number of white oak acorns for spring planting without germination and growth of radicles that were broken in handling. The amount of local seed we collected each fall varied greatly; some years only one tree we found had a good crop and other years many trees had acorns. All the white oak seed planted was rated excellent. It was not unusual to have acorns already germinating at fall planting.

Red oak—The sum of the areas of the rows of red oak seedlings or seed spots was 1.06 hectares planted to 1700 trees. Seedlings were donated by the Illinois state nursery. Quality of red oak nursery stock was rated fair for fall 1979, the season with the lowest later field survival, and otherwise good to excellent. We dug at the nursery the fall-lifted red oak seedlings for the test plantings. In fall 1978, 1979, 1980, and 1982 many seedlings when dug were still in leaf or even actively growing.

Red oak annual acorn crops varied substantially. If available they were planted both fall and spring. Missing seasons were fall 1978 and 1979, and spring 1980. Acorns were treated the same as white oak acorns, and for spring planting were stratified over winter in cold storage. The red oak seed planted was rated good to excellent. Germination after stratification was typically good, and ranged from 50 percent to over 90 percent in several seasons.

Herbicide Applications and Tree Counts and Measurements

Starting in spring 1981 all seedling and seed planting spots that had been planted either the previous fall or in the spring were sprayed in a 1.5 meter circle before tree growth began using a backpack sprayer with a mixture of glyphosate (Roundup®) and simazine (Princep®). Herbicide control was effective in the first year, and often not observable by the fourth year after planting. No further cultural practices were carried out.

All trees were counted for establishment the first summer after planting. If there was more than one seedling per seed spot, those of lesser vigor were clipped off at ground level. All trees were also counted and measured for height and basal caliper in year 3. As an example those planted in fall 1978 and spring 1979 were both measured in summer 1981. The number of trees established after 3 years was used to calculate the subsequent percent survival in 1993 shown in table 1. All trees were measured for height in 1988, and for height and diameter breast height (DBH), if that tall, in 1993 (Ashby and others 1995). Statistical methods were analysis of variance for heights and DBHs of several groupings of trees. Acorn production, animal damage if any, and other observations were recorded at each measurement and occasionally at other times.

RESULTS AND DISCUSSION

Relative Performance of White and Red Oak

Number of trees in 1993 of the 11- to 16-year-old Illinois white oak was 411 of 1800 planted (23 percent) and of red oak was 728 of 1700 planted (43 percent). Most of the losses of trees by 1993 took place in the first years after planting. Mortality from year 3 to 1993 was much lower, especially for red oak (table 1). Mortality was commonly several trees in a gap and canopy closure was found where trees were contiguous. If these white or red oaks had been planted solidly in a stand, a full forest canopy as found in pre-law plantings could be expected, even though higher planting rates would be needed for bond release.

Table 1—Percent of fall- and spring-planted white and red oak established at age 3 that survived to age 11-16 years when planted as seedlings or as seed

Season planted	White oak	Red oak
	------------- %	----------------
Seedlings		
Fall	85	98
Spring	79	95
Seed		
Fall	62	89
Spring	-	88

Tree form was good where trees were contiguous. Red oak would be the better choice for planting based on survival after establishment.

Irregularities in survival from year to year were found for both species (fig. 2). Some of the variability likely was related to undetected variation in planting-stock quality. Planting was carefully supervised with the planting crew supervisors and many of the planters the same from year to year. An important time-related factor that likely affected survival was weather conditions among the several planting seasons. April, May, and total precipitation were low in 1980, with only September at the end of the growing season relatively wet (figure 1). July, August, and September were so hot and dry that many corn fields were not harvested. The white oak seedlings that established in spring 1980 had relatively low survival at age 14. White oak growth was, however, not evidently suppressed (fig. 3), and the 14-year-old red oak trees were essentially equal in height to the 15- and 16-year-old trees (fig. 4).

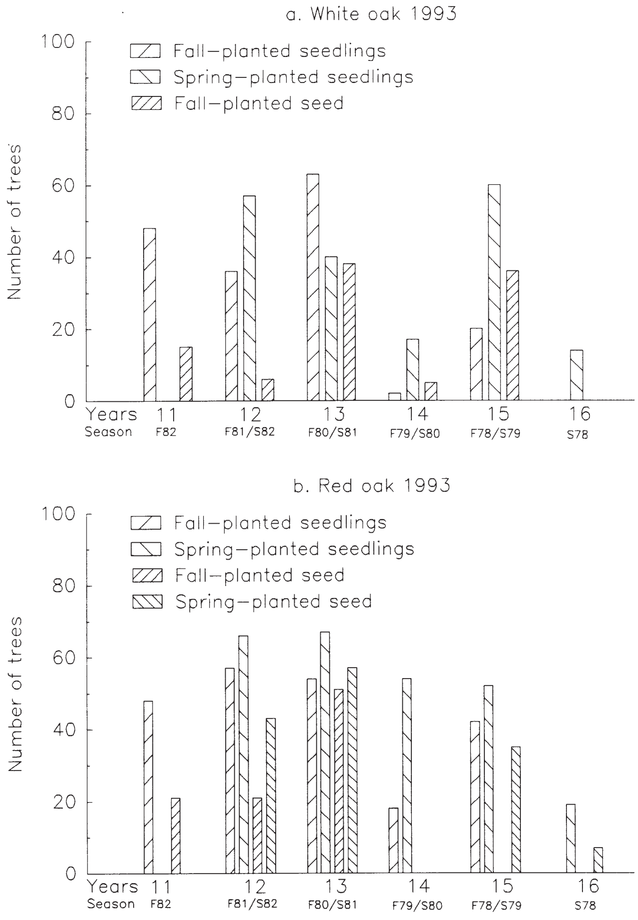

Figure 2—a. Average number of survivors in 1993 of 11- to 16-year-old white oak planted in fall or spring as seedlings or as seed. Each column is based on 100 seedlings or seed spots in 2 rows of 50 each planted per season.
b. Average number of survivors in 1993 of 11- to 16-year-old red oak planted in fall and spring as seedlings and/or as seed.

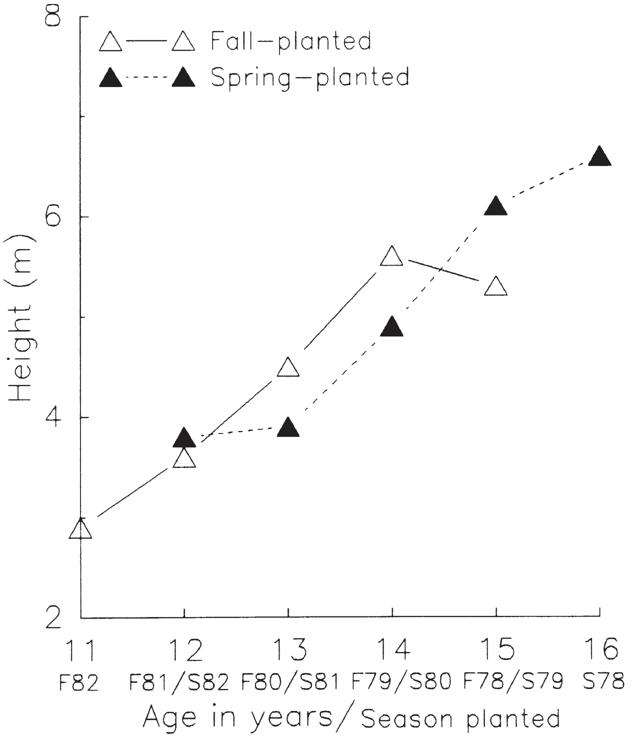

Figure 3—Average height in 1993 of 11- to 16-year-old white oak planted in fall or spring as seedlings or as seed.

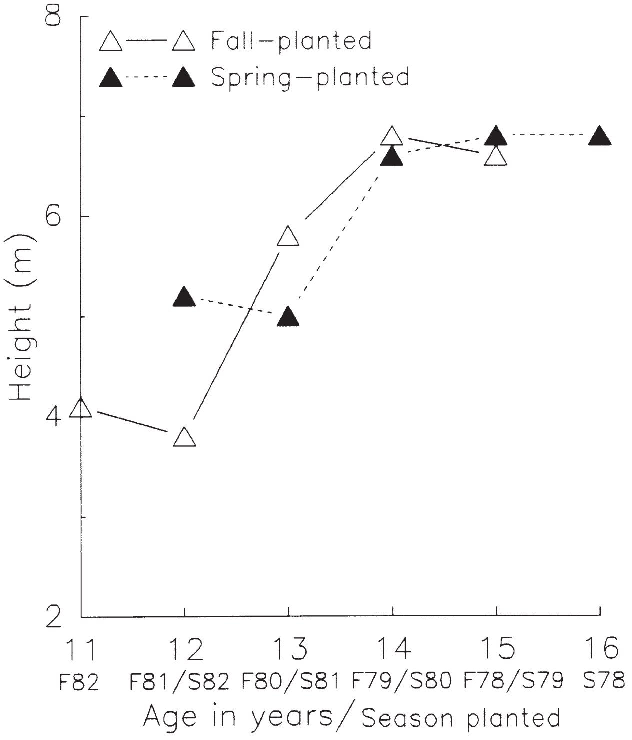

Figure 4—Average height in 1993 of 11- to 16-year-old red oak planted in fall or spring as seedlings or as seed.

A management change to application of herbicides happened only once. If no herbicide applications for trees ages 14, 15, or 16 years versus herbicide applications for trees ages 11, 12, and 13 years increased survival, it corresponded with greater expected survival of younger trees and did not seem to have done away with year-to-year variability.

Possible changes on a seasonal or yearly basis of spatial variation in properties of the successive plot areas planted on cast overburden for 5 years, or in competition from randomly assigned neighbors in the several plots, cannot be ruled out. Overall variation in topography or in observed spoil characteristics at the scale of an 0.7 hectare plot was not evidently synchronous with seasonal differences in survival and growth. The volunteer vegetation present seemed similarly heterogenous throughout the study area.

All the nearest neighbor species to each white and each red oak row were plotted. Neighbors were compared for oaks that had unusually low survival or growth performance in a given season. Any neighbor species consistently in common were, however, not found. For the seven lowest survival plantings, having one-fifth or fewer surviving trees in 1993 (fig. 2), most-common neighbors were four times black walnut planted as seedling or seed, three times each sycamore (*Platanus occidentalis* L.) or baldcypress, and two times or once nine other species. No neighbor species were in common for oak rows having unusually low height or DBH values. If there was a neighbor effect, how many years it would take to suppress growth of adjacent white or red oak is not known.

Relative height growth of the oaks was similar to survival. When all trees combined of each species are compared, white oak was significantly shorter (4.4 versus 5.4 meters) and differences in DBH (6.1 versus 6.0 centimeters) were not statistically significant. White oak planted as seedlings was, however, actively growing in years 15 and 16, while red oak had stagnated (figures 3 and 4). Reasons for the apparently lower heights of the 15- versus 14-year-old trees of both species from seed were not apparent. If growth criteria were of importance, choice of red oak with greater height may be offset by its apparent stagnation after age 14. Older trees of red oak produced acorns and could have enhanced forest succession if the mast had not been eaten or trampled by deer. Not much other animal damage was noted. Red oak typically has been much more damaged by deer than has white oak in stripmine plantings.

Tree Performance When Fall- versus Spring-Planted

Tree survival was highly variable with little consistency related to season. For example, white oak seedlings planted fall 1980 had the greatest number of trees and those planted fall 1979 the lowest (fig. 2). Red oak had the greatest number of trees when planted spring 1981 and the lowest when planted fall 1979 (fig. 2). Mortality after establishment was relatively similar for fall versus spring planting (table 1).

Average heights were lesser for fall- than spring-planted white and red oak seedlings and red oak planted as seed (table 2). DBH was greatest for spring-planted seedlings of both species, though not for spring-planted red oak seed. These averages mask year-to-year variability in relative heights, and DBHs not shown, of fall- versus spring-planted white or red oak (figs. 3 and 4).

Tree Performance When Planted as Seedlings versus Seed

Seedling versus seed differences were variable. Average percent survival tended to be lower for white versus red oak and greater for seedlings versus seed of both species (table 1). There was substantial variability. Number of surviving fall-planted white oak seedlings was greater than from seed at ages 11, 12 and 13 years, and vice versa at ages 14 and 15 years. Reasons for these differences were not evident. The few remaining white oak at age 14 had established in the dry, hot 1980 growing season. For the seasons when both were planted, red oak tended to have greater survival as seedlings than as seed.

The growth of either species from seedlings or seed was also irregular from year to year. White oak trees planted as seedlings were not significantly taller, or greater in DBH, than the averages of those planted as seed (table 3). Red oak seedlings tended to outgrow trees planted as seed when either fall- or spring-planted, and averaged significantly greater DBH when spring-planted.

In a recent survey of seven large coal companies, no local mine planted seedlings in the fall. Although seeding large-seeded tree species has been successful in the midwest, use of seed is unusual on local mines at present.

Table 2—Average height and dbh at age 11-16 years of white and red oak when fall- or spring-planted

Season planted	White oak		Red oak	
	Height	D.b.h.	Height	D.b.h.
	m	*Cm*	*m*	*Cm*
Seedlings				
Fall	4.1[a]	5.5[a]	5.1[a]	5.5[a]
Spring	4.9	7.1	5.9	6.8
Seed				
Fall	3.8	5.0	4.8[a]	5.0[b]
Spring	No seed planted		5.5	5.7
Seedlings and seed				
Fall	4.0	5.3	5.0[a]	5.4[a]
Spring	No seed planted		5.8	6.4

[a] Differences in paired means in a column were statistically significant at $p \leq 0.01$.

[b] Differences in paired means in a column were not statistically significant at $p > 0.05$.

Table 3—Average height and dbh at age 11-16 years of white and red oak when planted as seedlings or seed

	White oak		Red oak	
Season planted	Height	D.b.h.	Height	D.b.h.
	m	*Cm*	*m*	*Cm*
Fall-planted only				
Seedlings	4.1[a]	5.5[a]	5.1[a]	5.5[a]
Seed	4.9	7.1	5.9	6.8
Spring-planted only				
Seedlings	3.8	5.0	4.8[a]	5.0[b]
Seed	No seed planted		5.5	5.7
Fall- and spring-planted				
Seedlings	4.0	5.3	5.0[c]	5.4[b]
Seed	No seed planted		5.8	6.4

[a] Differences in paired means in a column were not statistically significant at $p>0.05$.
[b] Differences in paired means in a column were statistically significant at $p\leq0.01$.
[c] Differences in paired means in a column were statistically significant at $p\leq0.05$.

White Oak Performance with Alternative Growing Stock

Spring-lifted white oak seedlings held in cold storage over summer 1979, or summer 1980, and fall-planted had heights and DBHs similar to those regularly planted in the fall. Growth of Illinois and Missouri seedlings both planted in spring 1982 did not differ. These planting options offer important gains for successful tree planting and bond release on mined lands by extending the planting season. Stuart Miller, Missouri Department of Natural Resources, recently outlined his method for extending to spring the seed planting season with white oak, based on successful over-winter storage of acorns collected in the autumn before or as falling from the trees.

CONCLUSIONS

1. White oak seemed to be inherently less vigorous than red oak in survival and height, and not so in DBH.
2. Trees of both species fall-planted as seedlings or seed had lesser survival, height, and DBH than if spring-planted.
3. Trees of both species tended to have greater survival, height, and DBH when planted as seedlings than as seed.
4. Fall planting of seedlings and fall and spring planting of seed usefully extended our white and red oak reforestation program compared to usual reclamation practice.
5. White oak seedlings held from spring over summer in cold storage for fall planting can have growth equivalent to those regularly fall-planted.
6. Availability of either white or red oak seedlings and seed varied greatly from season to season.
7. Red oak on mined cast overburden produced acorns by year 15.

ACKNOWLEDGMENTS

The work of Clay Kolar and Gary Philo, former researchers in the Department of Botany, Southern Illinois University at Carbondale, contributed substantially to this paper. The Sahara Coal Company, Inc. funded much of the research, the Illinois Department of Conservation supplied tree seedlings, and the USDI Bureau of Mines funded the 1993 measurements.

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LONG-TERM EFFECTS OF WASTEWATER IRRIGATION ON FORESTED ECOSYSTEMS AT PENNSYLVANIA STATE GAME LANDS 176

David S. Larrick and Todd W. Bowersox[1]

Abstract—In 1983, the Pennsylvania State University engaged in a spray irrigation system for the disposal of treated wastewater on 209 hectares of farm and forest land in State Game Lands 176. The system was designed to distribute 5 centimeters of wastewater 52 weeks per year. Differences in species composition and structure have been observed between the irrigated and non-irrigated. In 1997, to monitor the long-term effects of wastewater irrigation on plant community and soil conditions in forested ecosystems, 20 pairs of irrigation and non-irrigation plots were established, and density and species composition of tree, shrub, and herbaceous plants were inventoried. Soil samples of A and B horizons were also taken for each 20 x 20 meters plot. At each plot, plants components included (1) overstory stems on 20 x 20 meters plot, (2) sapling-sized stems on four 10 x 10 meters subplots, (3) seedling-sized stems on four 2 x 2 meters subplots, (4) shrub species coverage on four 10 x 10 meters subplots, and (5) herbaceous plants coverage on sixteen 1 x 1 meters subplots. Initial results indicate striking differences in species composition, in densities of trees and shrubs, and in shrub and herbaceous coverage values, between the irrigated and non-irrigated forested communities. Total numbers of combined tree and shrub species in the non-irrigated overstory, sapling-sized, and seedling-sized components were 15, 47, and 33 species, respectively, compared to 17, 29, and 10 species, respectively, for the irrigated components. Overstory, sapling-sized, and seedling-sized stem densities were 536, 2,823, and 107,316 stems/hectares, respectively, for the non-irrigated and 361, 706, and 1,127 stems/hectares, respectively, for the irrigated components. Shrub and herbaceous coverage values were 17 and 80 percent, respectively, in the irrigated area, compared to 61 and 30 percent, respectively, in the non-irrigated area. The fertility levels in soil A and B horizons were also very different for the two areas. For both A and B soil horizons, the irrigated area had higher pH, higher phosphorus, magnesium, and calcium contents, and lower exchangeable acidity than the non-irrigated area. These data suggest that modifications to either the plant community species base or the methods of wastewater distribution will be needed to maintain forested ecosystems in the wastewater irrigation area of State Game Lands 176.

INTRODUCTION

Disposal of sewage effluent has become a problem for many municipalities due to population increases and stricter regulatory controls. Typically, wastewater from sewage treatment plants is discharged into rivers or lakes. However, this disposal method has often lead to environmental problems through the eutrophication of aquatic systems. An alternative method, disposal on land, has the potential advantages of reducing stream pollution and recharging ground water reserves (Sopper and Kardos 1973). Effluent disposal experiments conducted in forested areas have shown that spray irrigation with chlorinated sewage effluent caused changes in the structure and species composition of vegetation. Increased rate of tree growth, increased plant biomass, altered species composition of ground-level plants, and decreased production and survival of native shrub and tree species have been brought about by the addition of nutrients and water to soil and by ice damage during winter (Brister and Schultz 1981, Epstein and Sawhill 1977, Sopper and Kardos 1973).

In 1983, the Pennsylvania State University engaged a spray irrigation system for 209 hectares of farm and forest land managed by the Pennsylvania Game Commission (State Game Lands 176). The system is designed to distribute 5 centimeters of wastewater 52 weeks per year. About one-half of the current forest land was always forest land, whereas the other half had been used for agriculture. No actual inventories of the shrub and tree species composition and structure have been conducted, but there has been an observed difference between irrigated and non-irrigated areas. Observations suggested there has been increased mortality of the trees in the overstory of irrigated areas as compared to non-irrigated areas. It has also been observed that the understory of the irrigated forests has more herbaceous plants and fewer shrub and tree species stems than the nearby non-irrigated forests. Actual changes that have occurred to the areas that would be different from normal stand development are unknown. However, it is possible to compare the present conditions in similar irrigated and non-irrigated forests and to measure future changes in these two conditions. A project has been started to determine the long-term effects of wastewater irrigation on forested ecosystems by establishing and maintaining a program to monitor plant community and soil conditions in irrigated and non-irrigated forested areas. Results from the initial inventories are presented in this paper.

METHODS

The study area was located in central Pennsylvania, 2 kilometers north of State College. The gently rolling terrain was in the Ridge and Valley region (Lull 1968) on lands managed by the Pennsylvania Game Commission. The soil was Morrison sandy loam (Ultric, Hapludalf; fine, loamy,

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mixed, mesic). Site quality was about average, and if occupied by evenaged mixed oak stands, the site index would be about 65.

Ideally the sampling procedures and design would have been prepared prior to treatment but the effects of wastewater irrigation on forested ecosystems was not a concern in 1983. In July 1997, 20 pairs of irrigation and non-irrigation long-term monitor plots were established to inventory density and species composition of the tree, shrub and herbaceous plants in forested areas. The plots were paired on the basis of having similar physical site conditions, history of use, and perceived species conditions in 1983 when the irrigation system was engaged. Reasons for some forested areas to be irrigated and others not irrigated were only due to the design features of the irrigation network. Plots were established and inventoried according to the Storm and Ross (1992) protocol for monitoring vegetation on public lands. A total of 40, 20 x 20 meters permanent plots were used to inventory the overstory trees and shrubs. Species, diameter (at 1.3 meters above ground in centimeters), health class (healthy, dead, or injured), and type of injury (branch breakage, stem breakage, or stem decay) of all overstory stems (≥11 centimeters in diameter) were recorded. Each 20 x 20 meters plot was subdivided into four 10 x 10 meters subplots to acquire species and diameter of all sapling-sized stems and shrub coverage. Nested within each 20 x 20 meters plot were four 2 x 2 meters subplots, each located 5 meters from plot center along cardinal directions, to inventory abundance of seedling-sized stems. Each 2 x 2 meters subplot was further subdivided into four 1 x 1 meters subplots to inventory coverage of herbaceous groups (grass, broadleaf, moss, vine). A randomly selected soil sample was also taken from near the center of each plot. Soil from the A (0-4 cm below humus layer) and B (10-25 cm below humus layer) horizons was analyzed for pH, extractable phosphorus (kilograms/hectare), exchangeable calcium, magnesium, potassium and cation exchange capacity.

Analysis of variance was used to test for significant differences between irrigated and non-irrigated areas in mean (1) number of species, density, basal area and stocking of overstory stems,(2) number of species and density of sapling-sized stems, (3) number of species and density of seedling-sized stems, (4) shrub species and coverage, (5) herbaceous coverage, and (6) soil chemical properties. Significance at the 0.05 level was used in all cases. Using analysis of variance to test for significance between sample plots selected after treatment violates basic design requirements. However, the analyses were conducted to provide an expression of variability about mean values.

RESULTS AND DISCUSSION

Overstory Stems

A total of 17 tree species were inventoried on the 20 paired permanent overstory plots, with the irrigated and non-irrigated areas containing 15 and 13 species, respectively. There was no significant difference in number of tree species per plot between irrigated (4 species/plot) and non-irrigated (5 species/plot) areas (Table 1). Tree density (Table 1) in the non-irrigated area (531 stems/hectare) was significantly different from the irrigated area (355 stems/hectare). The non-irrigated area had more aspen (see Appendix 1 for scientific names), black cherry, and pine stems than the irrigated area (Table 2). Oak, red maple, and other trees were equally abundant in both areas. The irrigated area had more ash and hickory stems than the non-irrigated area, but the numbers of ash and hickory were low for both areas. The irrigated area (Table 3) had a lower proportion of healthy trees (64 percent) and a higher proportion of injured trees (29 percent) than the non-irrigated area (84 percent healthy and 9 percent injured). These data indicate poor health in the overstory of the irrigated area. Basal area (27 meters^2/hectare) and stocking (100 percent) were significantly greater in the non-irrigated area (Table 1) than in the irrigated area (19 meters^2/hectare basal area and 73 percent stocking).

Overstories in both the irrigated and non-irrigated areas had low numbers of shrub species (2 in both areas) and low shrub densities (6 and 5 stems/hectare, respectively). There were no significant differences between irrigated and non-irrigated areas in terms of shrub species, density, basal area, healthy, dead, or injured stems (Tables 1 and 3).

It appears that the forested areas in the irrigated area are developing an open, park-like overstory that is comprised of less healthy trees than adjacent non-irrigated areas. There seems to be a change in the species composition from the non-irrigated mixed hardwood-pine to red maple-pine-mixed hardwood in the irrigated areas. Overstory density of oak and red maple trees did not appear to be affected by irrigation.

Table 1—Mean[a] overstory (≥11 cm in diameter) number of species per 0.04 ha plot, density, basal area, and stocking for tree, shrub, and total species in irrigated and non-irrigated areas

Species group area	Number of species	Density	Basal area	Stocking
	Per plot	*Stems/ha*	*m^2/ha*	*Percent*
Tree				
Irrigated	4 a	355 b	19 b	73 b
Non-irrigated	5 a	531 a	27 a	100 a
Shrub				
Irrigated	<1 a	6 a	<1 a	-
Non-irrigated	<1 a	5 a	<1 a	-
Total				
Irrigated	5 a	361 b	20 b	73 b
Non-irrigated	5 a	536 a	27 a	100 a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 2—Mean density of overstory (≥11 cm in diameter) trees and shrubs by species group[a] in irrigated and non-irrigated areas

Species group	Area	
	Irrigated	Non-irrigated
	Stems/ha	
Trees		
Ash	11	1
Aspen	23	119
Black cherry	28	56
Hickory	14	1
Oak	74	70
Pine	82	161
Red maple	120	120
Other tree	3	3
Total tree	355	531
Shrubs		
Flowering dogwood	0	1
Sassafras	5	4
Striped maple	1	0
Total shrubs	6	5

[a] Hickory included mockernut and pignut; oak included black, chestnut, scarlet, and white; pine included pitch, Scotch, and eastern white; other tree included American beech, blackgum, slippery elm, and sweet birch (see Appendix 1 for scientific names).

Table 3—Mean[a] overstory (≥11 cm in diameter) tree, shrub, and total healthy, dead, and injured stems in irrigated and non-irrigated areas

Species group area	Healthy	Dead	Injured
	Pct		
Tree			
Irrigated	64 b	7 a	29 a
Non-irrigated	84 a	7 a	9 b
Shrub			
Irrigated	56 a	33 a	11 a
Non-irrigated	0 a	25 a	75 a
Total			
Irrigated	64 b	7 a	29 a
Non-irrigated	83 a	7 a	9 b

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Sapling-Sized Stems

A total of 51 sapling-sized tree and shrub species were inventoried, with the irrigated and non-irrigated areas containing 29 and 47 total species, respectively. Number of species per plot (Table 4) was significantly greater in the non-irrigated area (7 species/plot) than in the irrigated area (3 species/plot). Total density also was significantly different between the non-irrigated (2,823 stems/hectare) and irrigated (706 stems/hectare) areas (Table 4).

Of the 21 tree species inventoried, the irrigated area had 13 species, and the non-irrigated area had 19 species. There was a significant difference in number of tree species between irrigated (1 species/plot) and non-irrigated (3 species/plot) areas (Table 4). The 1,585 tree species stems/hectare in the non-irrigated area was significantly greater than the 309 stems/hectare in the irrigated area (Table 4). All tree species, except ash, had substantially lower numbers of sapling-sized stems in the irrigated area as compared to the non-irrigated area (Table 5). There were 118 ash stems/hectare in the irrigated area and 98 stems/hectare in the non-irrigated area. Birch, hickory, oak, and pine sapling-sized stems were present in the non-irrigated area but were nearly absent from the irrigated area (Table 5).

The total number of shrub species was 30. There were 16 and 28 shrub species inventoried in the irrigated and non-irrigated areas, respectively. Numbers of shrub species and shrub densities (Table 4) were significantly greater in the non-irrigated area (3 species/plot and 1,238 stems/hectare) than the irrigated area (1 species/plot and 397 stems/hectare). The non-irrigated area had an abundance of sapling-sized stems for a variety of shrub species, with Tatarian honeysuckle and sassafras being the most prevalent. Hophornbeam, Tatarian honeysuckle, and spicebush were the most common sapling-sized shrub species in the irrigated area. Autumn olive, blackhaw, blueberry, dogwood, privet, and sassafras were less common in the irrigated area than in the non-irrigated area (Table 5).

Table 4—Mean[a] number of species and density of sapling-sized (≥151 cm in height and <11 cm in diameter) tree, shrub, and total species in irrigated and non-irrigated areas

Species group area	Number of species	Density
	0.01/ha	Stems/ha
Tree		
Irrigated	1 b	309 b
Non-irrigated	3 a	1,585 a
Shrub		
Irrigated	1 b	397 b
Non-irrigated	3 a	1,238 a
Total		
Irrigated	3 b	706 b
Non-irrigated	7 a	2,823 a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

Table 5—Mean density of sapling-sized (≥151 cm in height and <11 cm in diameter) trees and shrubs by species group[a] in irrigated and non-irrigated areas

	Area	
Species group	Irrigated	Non-irrigated
Trees		
Ash	118	98
Birch	1	24
Black cherry	55	371
Hickory	4	13
Maple	113	850
Oak	7	171
Pine	1	44
Other tree	10	14
Total tree	309	1,585
Shrubs		
Autumn olive	3	56
Raspberry	9	89
Blackhaw	0	23
Blueberry	0	34
Dogwood	1	76
Hophornbeam	11	18
Privet	1	78
Rose	9	101
Sassafras	0	330
Spicebush	14	6
Tatarian honeysuckle	330	386
Other shrubs	19	41
Total shrubs	397	1,238

[a] Birch included paper and sweet; hickory included bitternut, mockernut, and pignut; maple included red and sugar; oak included black, chestnut, northern red, scarlet and white; other tree included American elm, aspen, basswood, black walnut, blackgum, and slippery elm. Dogwood included flowering and gray; other shrub included American chestnut, American hazel, apple, boxelder, buckthorn, common elderberry, cranberry, dwarf oak, hawthorn, Hercules'-club, Japanese barberry, mapleleaf viburnum, musclewood, red elderberry, red mulberry, striped maple, viburnum, and witch-hazel.

Seedling-Sized Stems

Of the 33 seedling-sized tree and shrub species inventoried, only 10 species occurred in the irrigated area, while all 33 species were inventoried in the non-irrigated area. There were significant differences in total species per plot and total density per hectare between the irrigated and non-irrigated areas (Table 6). The irrigated area contained less than 1 species/plot and had a density of 1,127 stems/hectare, whereas the non-irrigated area had 5 species/plot and 107,316 stems/hectare.

Table 6—Mean[a] number of species and density of seedling-sized (<151 cm in height) tree, shrub, and total in irrigated and non-irrigated areas

Species group area	Number of species	Density
	0.0004/ha	*Stems/ha*
Tree		
Irrigated	<1 b	501 b
Non-irrigated	3 a	77,970 a
Shrub		
Irrigated	<1 b	626 b
Non-irrigated	2 a	29,346 a
Total		
Irrigated	<1 b	1,127 b
Non-irrigated	5 a	107,316 a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).

The non-irrigated area contained 13 tree species, compared to only 6 species in the irrigated area. On a per plot basis, there were 3 tree species inventoried in the non-irrigated area, versus less than 1 species in the irrigated area (Table 6). Tree density in the irrigated area of 501 seedling-sized stems/hectare was essentially non-existent compared to the 77,970 stems/hectare in the non-irrigated area (Table 6). Seedling-sized stems in the non-irrigated area were dominated by maple, with abundant black cherry and oak (Table 7). Ash, black cherry, and maple were the most abundant species in the irrigated area. However, seedling-sized densities were much lower in the irrigated area for all of the tree species groups, with aspen, paper birch, and eastern white pine not recorded in the irrigated area.

Striking differences in the number of shrub species and densities of shrub species stems also occurred between irrigated and non-irrigated areas. Shrub species totaled 20 in the non-irrigated area and 4 in the irrigated area. Both the number of species/plot (2) and stems/hectare (29,346) in the non-irrigated area were significantly greater than the number of species/plot (<1) and stems/hectare (626) in the irrigated area (Table 6). There were 12 seedling-sized shrub species groups in the non-irrigated area, with good densities of blackberry/raspberry, blueberry, rose, sassafras, and Tatarian honeysuckle (Table 7). In the irrigated area, there were only four seedling-sized shrub species groups, and only Tatarian honeysuckle seemed to be somewhat tolerant of the conditions in the irrigated area.

Shrub Coverage

Over all size classes, the non-irrigated area contained 33 shrub species, compared to 20 shrub species in the irrigated area. There was a significant difference in number of shrub species per plot between irrigated (2 species/plot) and non-irrigated (6 species/plot) areas (Table 8). Shrub coverage in the non-irrigated area (61 percent) was significantly greater than in the irrigated area (17 percent) (Table 8). Tatarian honeysuckle had equal coverage values (13 percent, each) on both the irrigated

Table 7—Mean density of seedling-sized (<151 cm in height) trees and shrubs by species group[a] in irrigated and non-irrigated areas

Species group	Area Irrigated	 Non-irrigated
	------------- *Stems/ha* -------------	
Trees		
Ash	94	938
Aspen	0	250
Black cherry	219	21,750
Hickory	31	750
Maple	94	49,781
Oak	63	4,407
Paper birch	0	63
White pine	0	31
Total tree	501	77,970
Shrubs		
Autumn olive	0	563
Raspberry	0	15,531
Blueberry	0	3,406
Common elderberry	0	219
Cranberry	0	188
Dogwood	0	750
Japanese barberry	31	188
Rose	94	2,156
Sassafras	0	1,906
Tatarian honeysuckle	438	3,313
Viburnum	0	688
Other shrubs	63	438
Total shrubs	626	29,346

[a] Hickory included mockernut and pignut; maple included red and sugar; oak included black, chestnut, northern red, and white. Dogwood included flowering and gray; viburnum included mapleleaf and viburnum; other shrub included American chestnut, apple, blackhaw, hawthorn, hophornbeam, spicebush, and striped maple.

and non-irrigated areas, whereas the coverage values of blackberry/raspberry, rose, and sassafras were considerably lower in the irrigated area as compared to the non-irrigated area (Table 8). Coverage values of the other species were too low to evaluate any irrigation effects.

Herbaceous Coverage

Total herbaceous coverage (Table 9) in the irrigated area (80 percent) was much greater than in the non-irrigated area (30 percent), primarily due to a significant difference in broadleaf coverage (63 and 17 percent coverage in irrigated and non-irrigated areas, respectively). Vine and moss coverage values were slightly higher in the irrigated area (15 percent vine and 2 percent moss coverage) than the non-irrigated area (11 percent vine and 1 percent moss coverage). Each area contained less than 1 percent grass coverage.

Table 8—Combined mean coverage of overstory, sapling- and seedling-sized shrubs by species group[a] in irrigated and non-irrigated areas

Species group	Area Irrigated	 Non-irrigated
	------------ % coverage -----------	
Autumn olive	<1	2
Raspberry	1	19
Blueberry	<1	3
Dogwood	<1	3
Hophornbeam	1	<1
Japanese barberry	<1	1
Privet	<1	2
Rose	<1	7
Sassafras	0	9
Spicebush	<1	<1
Tatarian honeysuckle	13	13
Other shrubs	1	2
Total shrubs	17	61

[a] Dogwood included flowering and gray; other shrub included American chestnut, American hazel, apple, blackhaw, boxelder, buckthorn, choke cherry, common elderberry, cranberry, currant/gooseberry, dwarf oak, hawthorn, Hercules'-club, mapleleaf viburnum, musclewood, red elderberry, red mulberry, serviceberry, striped maple, sumac, viburnum, winterberry holly, and witch-hazel.

Table 9—Mean[a] broadleaf, grass, moss, vine, and total herbaceous coverage in irrigated and non-irrigated areas

Species group area	Coverage
	Percent
Broadleaf	
Irrigated	63 a
Non-irrigated	17 b
Grass	
Irrigated	<1 a
Non-irrigated	<1 a
Moss	
Irrigated	2 a
Non-irrigated	1 b
Vine	
Irrigated	15 a
Non-irrigated	11 b
Total	
Irrigated	80 a
Non-irrigated	30 b

[a] Means with the same letter are not significantly different (a = 0.05).

Soils

There were substantial differences between the irrigated and non-irrigated areas in the chemistry of soil A horizon (Table 10). The A horizon of the irrigated area had significantly higher soil pH (7.1), phosphorus (345 kilograms/hectare), magnesium (3.16 milliequivalent/100 grams), and calcium (9.78 milliequivalent/100 grams) than the non-irrigated area (4.8 soil pH, 48 kilograms/hectare phosphorus, 0.39 milliequivalent/100 grams magnesium, and 2.42 milliequivalent/100 grams calcium). The non-irrigated area had significantly higher exchangeable acidity (10.32 milliequivalent/100 grams) than the irrigated area (0.10 milliequivalent/ 100 grams). Potassium (0.19 milliequivalent/100 grams) and cation exchange capacity (13.22 milliequivalent/100 grams) for the irrigated area were not significantly different from the non-irrigated area (0.18 and 13.03 milliequivalent/100 grams potassium and cation exchange capacity, respectively).

For the B horizon (Table 10), the irrigated area had significantly higher soil pH (7.2), phosphorus (295 kilograms/hectare), potassium (0.18 milliequivalent/100 grams), magnesium (0.95 milliequivalent/100 grams), and calcium (2.41 milliequivalent/100 grams) than the non-irrigated area (5.0 soil pH, 45 kilograms/hectare phosphorus, 0.09 milliequivalent/100 grams potassium, 0.18 milliequivalent/100 grams magnesium, and 0.55 milliequivalent/100 grams calcium). The non-irrigated area had significantly higher exchangeable acidity (4.86 milliequivalent /100 grams) and cation exchange capacity (5.61 milliequivalent/100 grams) than the irrigated area (0.00 milliequivalent/100 grams exchangeable acidity and 3.52 milliequivalent/100 grams cation exchange capacity).

Differences between irrigated and non-irrigated areas were a direct reflection of the chemical composition of the wastewater additions, which had greater levels of phosphorus, magnesium and calcium than what would be found in rain water. The soil chemistry in the non-irrigated area was what would be expected for a soil that developed from acid sandstone. With the exception of potassium in the A horizon, soil chemical levels in the irrigated area were what would expected for a soil that developed from a calcareous parent material. Water for the Pennsylvania State University is from wells supplied from primarily limestone bedrock.

CONCLUSIONS

Initial results of the vegetation monitoring program at Pennsylvania State Game Lands 176 indicate substantial differences in species composition and densities of trees and shrubs between the wastewater irrigated and non-irrigated forested areas. Total numbers of combined tree and shrub species in the non-irrigated overstory, sapling-sized, and seedling-sized components were 15, 47, and 33 species, respectively, compared to 17, 29, and 10 species, respectively, for the irrigated components. Overstory, sapling-sized, and seedling-sized stem densities were 536, 2,823, and 107,316 stems/hectare, respectively, for the non-irrigated and 361, 706, and 1,127 stems/hectare, respectively, for the irrigated components. It appears that the forested areas in the irrigated area are developing an open, park-like overstory that is comprised of less healthy trees than adjacent non-irrigated areas. Shrub and herbaceous coverage values were 17 and 80 percent in the irrigated area, compared to 61 and 30 percent in the non-irrigated area. For both A and B soil horizons, the irrigated area had higher pH, higher phosphorus, magnesium, and calcium contents, and lower exchangeable acidity than the non-irrigated area.

Since there were no pre-wastewater irrigation inventories, we can not be certain that the differences after 15 years between the irrigated and non-irrigated areas were due to the application of wastewater. However, the evidence strongly supports that the differences are related to the year-long irrigation with 5 cm of wastewater per week. The reasons for these differences in the plant communities are not known. It is possible that the indigenous herbaceous, shrub, and tree species can not adapt to the enhanced nutrients and water from the irrigation system. There may be other herbaceous, shrub, and tree species that are

Table 10—Mean[a] chemical properties of soil A and B horizons[b] in irrigated and non-irrigated areas

Horizon area	pH	P	Acidity	K	Mg	Ca	CEC
		Kg/ha	------- Exchangeable cations (*meq/100 g*) -------				
Horizon A							
Irrigated	7.1a	345a	0.10b	0.19a	3.16a	9.78a	13.22a
Non-irrigated	4.8b	48b	10.32a	0.18a	0.39b	2.42b	13.03a
Horizon B							
Irrigated	7.2a	295a	0.00b	0.18a	0.95a	2.41a	3.52b
Non-irrigated	5.0b	45b	4.86a	0.09b	0.18b	0.55b	5.61a

[a] Means with the same letter are not significantly different ($\alpha = 0.05$).
[b] A horizon was 0-4 cm below humus layer; B horizon was 10-25 cm below humus layer.

capable of creating and maintaining an acceptable forest community in these amended conditions. It is also possible that the mechanics of the overhead spray of water may be causing physical damage to the plants or creating environments that are favorable for the development of undesirable insects or pathogens. Finally, it is also possible that the bending and breaking on the seedling-sized and sapling-sized stems from heavy ice loading may be selectively removing most of the tree and shrub species from the communities. Based on the data collected in this study, it is clear that modifications to either the plant community species base or the methods of wastewater distribution will be needed to maintain forested ecosystems in the wastewater irrigation area of State Game Lands 176.

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Appendix 1—List of total tree and shrub species

Tree Species

- American beech (*Fagus grandifolia* Ehrhart)
- American elm (*Ulmus americana* L.)
- ash (*Fraxinus* spp.)
- aspen (*Populus* spp.)
- basswood (*Tilia americana* L.)
- bitternut hickory (*Carya cordiformis* (Wangenheim) K. Koch)
- black cherry (*Prunus serotina* Ehrh.)
- black oak (*Quercus velutina* Lam.)
- black walnut (*Juglans nigra* L.)
- blackgum (*Nyssa sylvatica* Marshall)
- chestnut oak (*Quercus prinus* L.)
- eastern white pine (*Pinus strobus* L.)
- mockernut hickory (*Carya tomentosa* (Lam. ex Poir.) Nutt.)
- northern red oak (*Quercus rubra* L.)
- paper birch (*Betula papyrifera* Marshall)
- pignut hickory (*Carya glabra* (P.Mill.) Sweet)
- pitch pine (*Pinus rigida* P.Mill.)
- red maple (*Acer rubrum* L.)
- scarlet oak (*Quercus coccinea* Muenchh.)
- Scotch pine (*Pinus sylvestris* L.)
- slippery elm (*Ulmus rubra* Muhl.)
- sugar maple (*Acer saccharum* Marshall)
- sweet birch (*Betula lenta* L.)
- white oak (*Quercus alba* L.)

Shrub Species

- American chestnut (*Castanea dentata* (Marshall) Borkh.
- American hazel (*Corylus americana* Walt.)
- apple (*Malus* spp.)
- autumn olive (*Elaeagnus umbellata* Thunb.)
- blackberry/raspberry (*Rubus* spp.)
- blackhaw (*Viburnum prunifolium* L.)
- blueberry (*Vaccinium* spp.)
- boxelder (*Acer negundo* L.)
- buckthorn (*Rhamnus cathartica* L.)
- choke cherry (*Prunus virginiana* L.)
- common elderberry (*Sambucus canadensis* L.)
- cranberry (*Viburnum trilobum* Marshall)
- currant/gooseberry (*Ribes* spp.)
- dwarf oak (*Quercus prinoides* Willd.)
- flowering dogwood (*Cornus florida* L.)
- gray dogwood (*Cornus racemosa* Lam.)
- hawthorn (*Crataegus* spp.)
- Hercules'-club (*Aralia spinosa* L.)
- hophornbeam (*Ostrya virginiana* (P.Mill.) K.Koch
- Japanese barberry (*Berberis thunbergii* DC.)
- mapleleaf viburnum (*Viburnum acerifolium* L.)
- musclewood (*Carpinus caroliniana* Walter)
- privet (*Ligustrum obtusifolium* Sieb. & Zucc.)
- red elderberry (*Sambucus pubens* Michx. PFGBW)
- red mulberry (*Morus rubra* L.)
- rose (*Rosa* spp.)
- sassafras (*Sassafras albidum* (Nutt.) Nees)
- serviceberry (*Amelanchier arborea* (Michx.f.) Fern.)
- spicebush (*Lindera benzoin* (L.) Blume)
- striped maple (*Acer pennsylvanicum* L.)
- sumac (*Rhus* spp.)
- Tatarian honeysuckle (*Lonicera tatarica* L.)
- viburnum (*Viburnum dilatatum* L.)
- winterberry holly (*Ilex verticillata* (L.) A.Gray)
- witch-hazel (*Hamamelis virginiana* L.)

SURVIVORSHIP AND GROWTH OF NATURAL NORTHERN RED OAK (*QUERCUS RUBRA* L.) SEEDLINGS IN RESPONSE TO SELECTED TREATMENTS ON AN EXTREMELY ACIDIC FOREST SOIL

Michael C. Demchik and William E. Sharpe[1]

Abstract—Natural seedlings of northern red oak (*Quercus rubra* L.) growing on extremely acidic soils are subjected to stresses resulting from the relatively inhospitable soil chemical environment, competition from other plants and herbivory by white-tailed deer (*Odocoileus virginianus* Boddaert). The objective of this study was to determine if lime and fertilizer, fencing and vegetation control could increase the growth and survivorship of natural northern red oak seedlings. Three replicate plots for each possible combination of liming and fertilization (6600 kg/ha dolomitic lime, 110 kg/ha K_20 equivalents and 220 kg/ha P_2O_5 equivalents), vegetation control (removal of fern fronds) and fencing (woven wire fencing) were established in the spring of 1995. Two years after treatment, the area was subjected to a partial cut. Without any other site treatment, vegetation control increased mortality. Lime and fertilizer treatment increased height growth before and after cutting. Vegetation control increased height growth after cutting but had no effect on height growth prior to cutting. Fencing increased seedling height growth prior to and after cutting. Seedlings that were not fenced actually lost height in the year after cutting. While seedlings were responsive to treatment, the magnitude of the growth response was low.

INTRODUCTION

Northern red oak (*Quercus rubra* L.) is a major component of mature forest stands in southwestern Pennsylvania. Oak is a valuable species for both timber and wildlife; therefore, inclusion of a large component of oak in forest regeneration after logging is an important goal of forest management in these forests. However, on many sites in Pennsylvania, northern red oak is often only a minor component of seedling regeneration (McWilliams and others 1995). Historically, 75 percent of the regeneration that developed into the current oak overstory was seedling origin (McIntyre 1936) but regeneration following recent harvests is often less than desirable. Several factors have been hypothesized to explain this lack of regeneration success. These include competition with hayscented ferns (*Dennstaedtia punctilobula* (Michx.) Moore); (Horsley 1993; Lyon 1996), browsing by deer (*Odocoileus virginianus* Boddaert); (Tilghman 1989; Marquis and Brenneman 1981) and acidic, infertile soil (Demchik and Sharpe 1996; Lyon 1996; Cronan and Grigal 1995; Joslin and Wolfe 1989).

Competition by hayscented fern is capable of impeding success of forest regeneration. Horsley (1993) has documented that although black cherry (*Prunus serotina* Ehrh.) seeds germinate after cutting, they are out-competed by hayscented fern. One factor in this competition is light. Light competition has been suggested as an important factor by Hippensteel and Bowersox (1995). They showed inhibition of white ash (*Fraxinus americana* L.) seedlings by altered light quality; however, they also reported the existence of a non-specific below ground competition. Lyon and Sharpe (1996) also found that hayscented fern limited northern red oak seedling growth as a consequence of below ground competition.

Deer browsing also constitutes a serious limitation to regeneration of oaks (Tilghman 1989; Marquis and Brenneman 1981). Both oak stump sprouts and seedlings are extensively browsed. However, even when deer browsing is limited by electric fencing, regeneration of oaks may not be successful (Demchik and Sharpe 1996; Lyon and Sharpe 1995).

Low levels of available soil bases and high levels of available aluminum may reduce the growth rates of northern red oak (DeWald and others 1990; Joslin and Wolfe 1989). Extremely acidic forest soils often have quite low levels of available calcium and high levels of available aluminum. The potential for aluminum toxicity exists when this occurs (Cronan and Grigal 1995). Indeed, Joslin and Wolfe (1989) found a reduction of growth (at ambient aluminum levels) due to increases in levels of aluminum in their test soils.

Attempts to increase growth of northern red oak seedlings with addition of lime and fertilizer have been largely successful in greenhouse trials, but field results have been mixed (Hart 1995; Hart and Sharpe 1997; Sharpe and others 1993; Pickens 1995). While field results have varied, amelioration of soil base nutrient deficiency and aluminum toxicity remains a promising technique for improving oak seedling growth.

Our study site was located in the Laurel Hill region of southwestern Pennsylvania. This region contains soil horizons with relatively high plant available Al and low Ca (Lyon and Sharpe in press; Demchik and Sharpe 1996).

The objective of this study was to determine if lime and fertilizer, fencing and vegetation control could increase

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growth and survivorship of natural northern red oak seedlings.

METHODS

The Site

An 80-85 year old stand of hardwoods was selected on the Laurel Hill in southwestern Pennsylvania. The stand was composed of 67 percent northern red oak (average diameter of 31.5 cm), 22 percent red maple (*Acer rubrum*; average diameter of 15.9 cm), 7 percent black cherry (average diameter of 30.4 cm) and 2 percent other species. There was an average of 291 trees/ha. The land was mildly sloping (0-20 percent), northeast facing ridgetop. The area is part of Pennsylvania's State Forest system managed by the Pennsylvania Bureau of Forestry. The soils are Typic Dystrochrepts of the Dekalb very stony loam series. Results from 10 hand excavated soil pits on the site revealed a mean organic layer thickness of 4.7±1.4 cm and A-horizon thickness of 7.1±3.6 cm. Site index (50 year) for oak was 19.5 - 22.5 meters. Data from an adjacent site showed soil pH values of the mineral horizon averaged 4.2 and base saturation was 3.1 percent of total exchange sites.

The site had received a light shelterwood cut 7 years prior to the beginning of this experiment, which reduced the basal area to approximately 18 m^2/ha. In addition, a salvage cut was made 3 years prior to this experiment to remove dead and dying trees. The cause of this mortality was unknown. Even though the understory cover was dominated by hayscented fern, northern red oak seedlings averaged 56,000±1000 /ha.

The Design

Twenty-four 1.25 m^2 plots each containing a minimum of 10 natural northern red oak seedlings each were established. All seedlings on the site were small (none taller than 25 cm). Ten randomly selected seedlings were tagged in each plot. These seedlings were measured for height and number of leaves immediately prior to treatment for use as a covariate. Three replicate plots of all possible combinations of the binary treatments of soil amendment, fencing and vegetation control were created. The soil amendment treatment consisted of an application of 6600 kg/ha dolomitic lime (53.5 percent calcium carbonate; 42.0 percent magnesium carbonate; 105.6 percent total calcium carbonate equivalents), 110 kg/ha K_2O equivalents and 220 kg/ha P_2O_5 equivalents applied in mid-May (shortly after bud break) or a control with no amendment. On an adjacent site, this application increased A-horizon soil pH from 4.1±0.04 to 4.5±0.04 and increased base saturation from 3.2±0.3 percent to 15.8±2.5 percent (Demchik 1998). Fencing consisted of encircling the plots with 1.25 meter tall 5 cm woven wire secured to iron reinforcement bars or a control with no fence. Vegetation control consisted of removal of all fern fronds within the plots as they appeared (approximately 3 times annually) or no vegetation control. Measurement of height, number of leaves and total leaf area of each plant was conducted in mid-August for three growing seasons. After 19 months (mid January 1997), the surrounding stand was cut to a residual of 13 m^2/ha basal area. Bolewood was removed and slash was left on site. Care was taken not to damage any of the seedlings. Nested ANCOVA was used for analysis of seedling height in a nested factorial design. Survivorship was tested with Chi-square test.

RESULTS AND DISCUSSION

Mortality

During the first growing season, no mortality occurred from the time of treatment until mid-August. During the second growing season, overall mortality was approximately 7.5 percent. No significant difference existed for mortality between treatments (Table 1). For the third growing season (first season after partial cutting), the highest mortality occurred in plots that were not limed and fertilized or fenced but received vegetation control (65 percent) (Table 1). This treatment combination consistently had the greatest mortality. Fenced plots had lower mortality (23 percent) than unfenced plots (39 percent). This response was primarily driven by the high rate of mortality for the plots that only received vegetation control (65 percent). With exclusion of these plots, unfenced plots had 30 percent overall mortality. This rate of mortality was similar to the rate for fenced plots. Plots that were limed and fertilized had less mortality (26 percent) than those that were not limed and fertilized (36 percent). When the treatment combination of no lime and fertilizer, no fencing but vegetation control was excluded rates of mortality were similar (both 26 percent).

The treatment of only vegetation control resulted in the greatest mortality. When vegetation control was applied with fencing, the rate of mortality was similar to all other treatments. Exposure of seedlings to deer browsing was therefore suggested as a contributing factor in the increased mortality on the vegetation control plots, perhaps because seedlings were more visible to the deer. This is consistent with the observations of other researchers (Tilghman 1989; Marquis and Brenneman 1981). Annual seedling mortality, even in control plots, was generally less than 15 percent before cutting and less than 40 percent after cutting, excluding the vegetation control treatment plots. This suggested that northern red oak seedlings could persist under the adverse conditions present on this site. Seedling red oaks are moderately shade tolerant (Phares 1971) and can remain viable under moderate light conditions for 8-10 years in the understory (McQuilkin 1983). However, in order for seedlings to be successful, they must grow at suitable rates.

Height Growth

Prior to partial overstory cutting, unfenced seedlings grew more slowly (annual growth of 0.8±0.04 cm) than fenced seedlings (annual growth of 1.3±0.05 cm); ($p<0.05$) (Table 2). After cutting, unfenced seedlings lost 1.1±0.06 cm of height and fenced seedlings gained 3.5±1.0 cm of height ($P<0.0001$) (Table 2). Deer browsing is well known to reduce success of forest regeneration (Tilghman 1989; Marquis and Brenneman 1981). The slow growth of fenced seedlings was surprising. When free from deer browsing, these seedlings only grew an average of 3.5 cm. This

Table 1—The effect of all possible combinations of lime and fertilizer (L&F), vegetation control (weed) and fencing on annual percentage mortality of northern red oak seedlings for two years prior to partial overstory cutting (1995 and 1996) and 1 year after partial overstory cutting (1997). Mortality is based on number of seedlings alive at the previous census

			Annual mortality		
L&F	Weed	Fencing	1995	1996	1997
			-----------*Percent*-----------		
No	No	No	0	7	23
No	No	Yes	0	13	27
No	Yes	No	0	25	65
No	Yes	Yes	0	0	27
Yes	No	No	0	7	37
Yes	No	Yes	0	0	15
Yes	Yes	No	0	0	30
Yes	Yes	Yes	0	10	23

Table 2—The effect of all possible combinations of lime and fertilizer (L&F), vegetation control (weed) and fencing on height growth of northern red oak seedlings for two years prior to partial overstory cutting (1995 and 1996) and 1 year after partial overstory cutting (1997). Annual growth is included for comparison because initial seedlings height was variable

			Total height				Annual growth		
L&F	Weed	Fence	Initial	1995	1996	1997	1995	1996	1997
			------------*Cm*------------						
No	No	No	14.0	14.9	15.7	13.9	0.9	0.8	-1.8
No	No	Yes	12.2	13.1	13.8	16.2	0.9	0.7	2.4
No	Yes	No	12.8	13.8	13.0	12.0	1.0	-0.8	-1.0
No	Yes	Yes	14.1	15.1	17.7	21.5	1.0	2.6	3.8
Yes	No	No	12.6	13.8	15.9	15.4	1.2	2.1	-0.5
Yes	No	Yes	12.0	12.2	14.2	18.1	0.2	2.0	3.9
Yes	Yes	No	14.1	14.1	15.5	14.5	0.0	1.4	-1.0
Yes	Yes	Yes	14.0	14.8	17.1	20.8	0.8	2.3	3.7

result suggested that deer browsing was not the only mechanism responsible for slow growth of these seedlings.

Vegetation control had no effect on height growth prior to cutting (1.1±0.06 cm for both). After cutting, seedlings that received vegetation control added more height growth (1.4±0.1 cm) than those that did not receive vegetation control (1.0±0.07 cm); ($P<0.05$) (Table 2). While these seedlings were responsive after cutting to release from aboveground competition by ferns, the magnitude of the response was small. Possibly, below ground competition was responsible for the limited response of these seedlings. Hippensteel and Bowersox (1995) found a non-specific competition between white ash (*Fraxinus americana* L.) and hayscented fern even when the fronds were removed. Likewise, Lyon and Sharpe (1996) reported below ground competition between northern red oak seedlings and hayscented ferns. While below ground competition was not tested, herbicide treatment as opposed to the frond removal treatment used in this study may generate a different response by eliminating below ground fern competition.

A vegetation control by fencing interaction was found for seedlings in 1996 and 1997. The seedlings in unfenced plots that received vegetation control grew the most slowly overall. These seedlings also experienced the highest rates of mortality. We believe that these slow growth rates and high rates of mortality are due to increased deer browsing.

Seedlings that were limed and fertilized grew more quickly prior to cutting (1.3±0.05 cm) and after cutting (1.5±0.06 cm) than those that were not limed or fertilized (0.9±0.06 cm and 0.9±0.05 cm, respectively); ($P<0.05$) (Table 2). While a response to soil amendments was found for these seedlings, its magnitude was small. These results are puzzling, since, in a companion study with planted 2-0 northern red oak nursery stock, similar treatment produced mean total 3 year growth of 61.8 cm (Sharpe and others 1998). Additional research will be necessary to ascertain why these differences were observed.

Overall, while these seedlings were responsive to all treatments, even the best possible combinations of treatments resulted in less than 4 cm of annual height growth. This rate is far from adequate. All of the factors that we addressed increased growth; however, it was apparent that additional requirements must be met to achieve a suitable rate of height growth.

Leaf Area

During the entire experiment, fenced seedlings increased in leaf area (18±6 cm^2; 64±10 cm^2, respectively) and unfenced seedlings lost leaf area (-135±20 cm^2; -180±25 cm^2, respectively) (Table 3). The factors of vegetation control and of lime and fertilizer were of limited importance to leaf area. Since deer browsing was responsible for negative height growth, reduction in leaf area would also be expected.

CONCLUSIONS

Without any other site treatment, vegetation control increased rates of mortality of natural northern red oak seedlings. Lime and fertilizer treatment increased height growth before and after cutting. Vegetation control increased height growth after cutting but had no effect on height growth prior to cutting. Fencing increased seedling height growth prior to and after cutting. Seedlings that were not fenced actually lost height in the year after cutting. While this investigation revealed statistically significant height growth gains in response to the treatments employed, the magnitude of these responses was low. Since the best growth rates were still less than 4 cm per year, other factors must have also limited height growth of these seedlings. These factors may have included but were not limited to light, soil moisture, other limiting nutrients and insect herbivory.

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Table 3—The effect on total leaf area (cm^2) of all possible combinations of lime and fertilizer (L&F), vegetation control (weed) and fencing on leaf area growth of northern red oak seedlings for two years prior to partial overstory cutting (1995 and 1996) and 1 year after partial overstory cutting (1997). Annual growth is included for comparison because initial seedlings height was variable

			Total leaf area			Annual growth	
L&F	Weed	Fence	1995	1996	1997	1996	1997
			---Cm²---				
No	No	No	227	162	82	-65	-80
No	No	Yes	99	99	172	0	73
No	Yes	No	113	109	76	-4	-33
No	Yes	Yes	160	161	288	1	127
Yes	No	No	150	129	108	-21	-21
Yes	No	Yes	144	146	189	2	43
Yes	Yes	No	175	130	84	-45	-46
Yes	Yes	Yes	142	209	223	67	14

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JAPANESE AND GIANT KNOTWEED SEED REPRODUCTIVE ECOLOGY

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Abstract—Japanese knotweed (*Polygonum cuspidatum* Sieb and Zucc.) and Giant knotweed (*Polygonum sachalinensis* F. Schmidt ex Maxim) are invasive, exotic perennials. They were introduced from eastern Asia as ornamental plants. These species were found throughout Pennsylvania especially along riparian, roadway, and railway corridors, and in waste areas. Japanese and Giant knotweed propagate asexually by rhizomes and basal buds. Researchers in the United Kingdom reported no viable seed set on Japanese knotweed due to the absence of male-fertile plants. In New Jersey, seedlings were found under Japanese knotweed. This research project was conducted to determine if the prolific seed produced within Pennsylvania was viable and capable of germinating in nature.

The reproductive ecology of Japanese and Giant knotweed seed was studied in eighteen populations from three river drainages across Pennsylvania. Field investigations showed that Japanese and Giant knotweed plants produce millions of seed annually. Two-year-old seedlings were discovered at four study sites in 1997 and 1998. Apparent viability assessments of seeds were made using seed coat and endosperm conditions. Seed coat was not a consistently good indicator of seed viability. Germination requirements were determined by testing the effects of moisture, temperature, and wing treatments on four seed sources over 30, 75, and 120 day storage periods. The temperature and moisture treatment combinations were all sufficient for germination. The overall mean germination rates were above 84 percent. Significantly different results were achieved with cold (3 degrees Celsius) moist conditions, yielding 95 percent mean germination over all storage times. Seedbank studies were conducted to determine the existence of naturally occurring knotweed seedbeds at four sites. The range of seedlings per soil core was 0-120. This equates to greater than 5,000 potential seedlings per square meter at the Rothrock and Lumber Road sites. Japanese and Giant knotweed were capable of reproducing sexually in these experiments.

INTRODUCTION

Japanese and Giant knotweed have established populations in a variety of habitats across Pennsylvania. They grew especially well in riparian zones, on strip-mine spoils, and on roadway and railway fill material. Their capabilities to out-compete and to displace other vegetation were obvious. Long stretches of the Susquehanna and Delaware River corridors were covered by both species. Large stands existed in the Allegheny Portage Railroad National Historic Site Staple Bend Tunnel Unit and Delaware Water Gap National Recreation Area. Japanese and Giant knotweed propagated vegetatively by extensive root systems. Researchers in the United Kingdom reported no viable seed on Japanese knotweed due to the absence of male-fertile plants. The small quantities of seed that were found were the result of hybridization with other members of *Polygonaceae*. A researcher in New Jersey reported seedlings under stands of Japanese knotweed (Locandro 1973). The observed prolific seed set on populations in the Northeastern United States warranted further investigation into the potential for reproduction from seed.

Japanese and Giant knotweed are rhizomatous perennials that form dense clumps and reach heights of 2.5 and 4 meters, respectively. Plants develop woody stocks with thick, bamboo-like, hollow stems that are erect and branched at the top. Perennating buds form at the base of the stem and on woody rhizomes between autumn and winter, and emerge as vertical shoots the following spring (Beerling and others 1994). Populations usually consist of parent plants called ramets. The vegetative shoots that grow from the ramets are called genets (Richards 1986). Stocks can produce prolific, creeping rhizomes within one year. Japanese knotweed leaves are truncate at the base, 5-15 centimeters long and 2-10 centimeters wide (Mitchell and Dean 1978). Giant knotweed leaves are cordate based, up to 40 centimeters long, and 22 centimeters wide. Japanese knotweed is functionally dioecious in the United States. It is gynodioecious (male-sterile and hermaphroditic individuals) in the United Kingdom (Beerling and others 1994). Giant knotweed is dioecious, possibly polygamous when hermaphroditic flowers are produced (Bailey 1994). Achenes are dark, glossy brown, 2-4 millimeters long and 2 millimeters wide. The hybrid between Japanese and Giant knotweed, *Fallopia x bohemica* (Chrtek & Chrtková)J.Bailey, is intermediate in growth habit and leaves (Bailey and Stace 1991).

Germination research on Japanese knotweed seed has been conducted in the United States. Germination of 84-100 percent was obtained after storage in air-dryness at room temperature for five months, and at 2-4 degrees Celsius in water, in moist peat, and between layers of moist cotton for three months (Justice 1941). Light versus dark tests resulted in higher percentages of seeds germinating in lighted conditions (61 percent) as opposed to dark conditions (13 percent) (Seiger 1993). However, Locandro (1973) found no significant differences due to

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light and temperature conditions in Japanese knotweed seed germination. Germination trials were conducted without light and exhibited high percentages of germination.

Seiger (1993) had higher germination rates with two-year-old seeds (54 percent) than with two-week-old seeds (3 percent). Locandro (1973) found a decline in percent germination after 270 days in storage. Significant differences were noted due to the different storage and cold treatment periods, prior to germination trials. Locandro (1973) reported that germination continued to increase with longer periods of cold treatment. Germination was poor after one year of seed storage at 18 degrees Celsius and 32 percent humidity. Cold treated seed reacted differently than non-cold treated seed after 30, 60, and 90 days of storage. Germination increased with pre-chill treatments of 60 and 90 days (Locandro 1973).

It was not known if Japanese and Giant knotweed growing within Pennsylvania was capable of producing viable seed, and if the potential seedlings were capable of becoming established under natural conditions. The specific objectives of this study were: to determine the potential for seed reproduction from Japanese and Giant knotweed populations, and to evaluate the potential for the natural establishment of knotweed seedlings beneath or adjacent to seed producing populations in Pennsylvania.

METHODS

Field Sites

Eighteen field sites containing populations of Japanese and Giant knotweed were chosen across Pennsylvania. Figure 1 shows the location of the sites and the watershed designations. The majority of locations were within or near these National Park Service properties: Allegheny Portage Railroad National Historic Site, Delaware Water Gap National Recreation Area, and Valley Forge National Historic Site.

The sites were in the Delaware, Ohio, and Susquehanna River watersheds. Descriptions of the habitat and morphology of the knotweed plants were recorded over two years. Four of the seven sites in the Susquehanna River drainage were within 30 meters of water. The Delaware River drainage sites were within 5 meters of water, except Bushkill Church which was on abandoned fill. The Ohio drainage populations were in mixed settings. Johnstown and Saint Michael were within 10 meters of a stream, while Staple Bend was approximately 150 meters from a river. Bitumen and Lumber Road were in very remote forest locations on roadway material (gravel and soil mixed).

Flower development, sex, and the general location of male and female plants were recorded in July and August at each site. At that time, differences in leaf size and shape, and stem height were recorded to aid in species

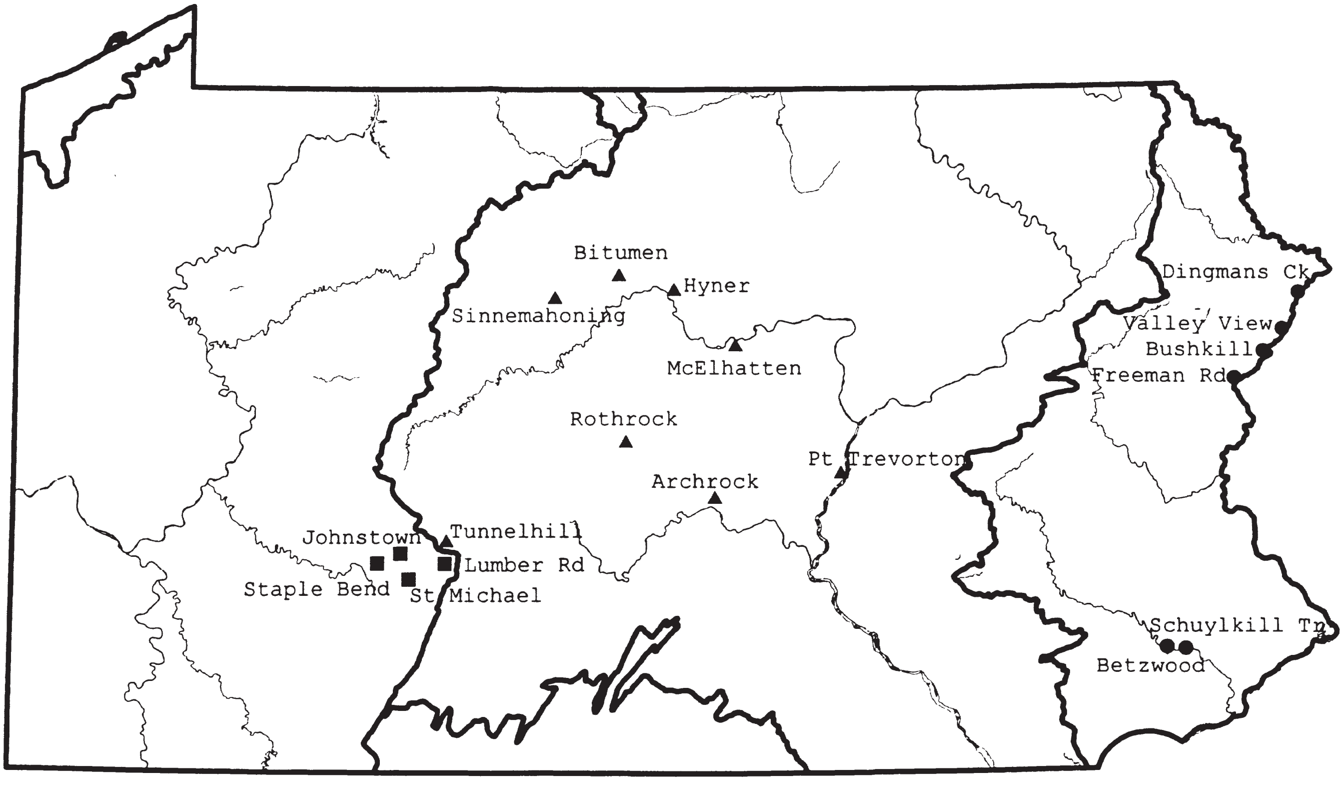

Figure 1—Locations of field sites in the Ohio River (squares), Delaware River (circles), and Susquehanna River (triangles) watersheds.

identification. The most reliable characteristics for the identification of the species and the hybrid were leaf shape and size. Only mature basal leaves were used because immature and upper leaves were extremely variable (Bailey 1988b). Botanical keys for the identification of *Polygonum* species differentiated between Japanese and Giant knotweed by truncate and cordate leaf bases (Mitchell and Dean 1978, Wofford 1989). Knotweed seeds were collected in September and October of 1996 and 1997. The amount of seed produced at each site varied widely. Single stems produced 50,000-150,000 seeds annually. Millions of seeds were produced over a 10 square meter area at locations such as Lumber Road, Staple Bend, and Rothrock. Seed collections were random samples of whole inflorescences from different plants. Seeds were air dried, and stored with either the wing intact (natural seed) or dewinged (achene only).

Apparent Viability

Visual assessments of seed viability were based on seed coat and endosperm conditions. Estimates of viability were made on random samples of 100 seeds from each source collected in 1996. The seeds were inspected under a dissecting scope. The conditions of the seed coat and endosperm were evaluated. Seed coats were described as normal (hard), soft, or shrunken. Endosperm content was estimated as full, half, or absent, and the color was classified as cream or white. Similar seed viability assessments were made on the 1997 seeds using 25 seeds per source. Percent viability was based on the number of seeds having normal seed coats and full endosperm. Tetrazolium chloride tests on endosperm viability were not used because Locandro (1973) reported poor results with the method.

Germination Studies

Four seed sources (Rothrock, Staple Bend, Port Trevorton, and Bitumen) were used to test different seed storage regimes. The seeds used in the germination trials were stored at room temperature for 100 days after collection. To test the effect of wing inhibition, seeds were either left natural (wing intact) or dewinged (achene only) by means of friction. The presence of the papery wing could inhibit both water absorption by the seed coat and radicle emergence. The seeds were stored for 30, 75, and 120 days under three different environmental conditions: warm-dry, cold-dry, and cold-moist (18, 3, and 3 degrees Celsius, respectively) (Table 1). Warm-moist, 18 degrees Celsius, conditions resulted in immediate germination of seeds. Refrigerated seeds were placed in plastic bags containing sand moistened with distilled water. All bags were then placed in glass jars and sealed. Sterile petri dishes, 9 centimeters in diameter, were lined with 9 centimeter diameter, grade 4 filter paper. Random samples of 40 seeds were placed into 96 dishes and covered with another filter paper. Three milliliters of distilled water was poured over the filter paper to provide moisture. Each dish was placed in a quart size plastic bag with a wet paper towel as a supplemental moisture source. Twenty four dishes were arranged in randomized block designs on 4 trays (4 replications). The trays were placed in a growth chamber at 27 degrees Celsius.

Light was not provided in the growth chamber. The basis for determining if a seed had germinated was radicle and cotyledon emergence. The number of germinates was recorded in each dish every three days over a fourteen day period. The seeds were exposed to fluorescent light during the counts. The number of seeds used in each environmental condition was 3,840, for a total of 11,520.

The percent germination values were log transformed. Analysis of Variance (alpha=.05) was run to test the effects of seed source, seed condition, environmental condition, and all of the interactions on seed germination. Tukey's HSD mean separation procedures were used to determine significant differences (alpha=.05).

Viability Germination Trials

The reliability of using seed coat condition as an indicator of seed quality was tested on seeds collected in 1997. All seeds had been stored under dry, room temperature conditions for 60 days prior to testing. Random samples of 50 seeds were taken from each source. The seed coats were determined to be either normal or shrunken. The seeds were separated as such and put between layers of wetted filter paper in petri dishes. The growth chamber conditions were 27 degrees Celsius and 66 percent humidity. The number of germinates was recorded every four days for a sixteen day period. Chi Square 2-way Test of Independence (Little 1978) was used to evaluate the ability to determine seed viability based on seed coat condition.

Table 1—Experimental design of seed germination trials conducted in 1997 on Giant and Japanese knotweed seed collected in 1996

Variables	Number	Treatments
Seed sources	4	Bitumen, Staple Bend, Rothrock, Port Trevorton
Seed conditions	2	Whole seed, achene only
Environmental conditions	3	Warm-dry, cold-dry, cold-moist
Storage times	3	30, 75, 120 days
Replications	4	

Soil Core Studies

Two hundred soil cores from four study sites, known to have produced viable seed in the Fall of 1996, were collected in the Spring of 1997. Staple Bend, Rothrock, Lumber Road, and Bitumen sites were used in this study. Two hundred soil cores (15 centimeters diameter, 10 centimeters deep, 182 square centimeters) were transported to a greenhouse and placed into commercial potting media to ensure adequate moisture. The cores were collected with intact (minimally disturbed) soil profiles. The randomized block design had five replications of ten cores per soil source. The number of knotweed seedlings that emerged was recorded from May 25 to August 15. The June 20 data was used for analysis, since there were no net changes in the number of seedlings per core after that date. The total number of seeds within the soil was not counted.

RESULTS AND DISCUSSION

Field Sites

The natural variation that occurs within a plant community, phenotypic plasticity, made identification of species difficult. Mature basal leaves were reliable indicators of species and were used to identify Japanese and Giant knotweed and the hybrid. Differences in stem height, leaf shape, and leaf size were recorded at each site.

Table 2 summarizes the locations and morphological characteristics of the plants found at the sites. There were 10 Japanese knotweed sites, 7 Giant knotweed sites, and 1 hybrid site. The Japanese knotweed populations had maximum heights of 3 meters. The tallest Giant knotweed plants were located at Staple Bend, Sinnemahoning, and Bitumen, all of which had maximum heights of 4 meters.

An abundance of seeds were produced when both female and male- fertile plants were present at a site. The intermingling of the two plants resulted in higher quantities of seed than if the plants were spatially separated. The amount of seed produced is expressed as seed crop values based on an average of 1,000 seeds per raceme (Table 2). Plants at every study sites produced seeds during the first year of research. No viable seeds were found when male-fertile plants were absent from the site. No viable seeds were found at the Valley View and Archrock sites in 1996, all of the seeds were empty. No seeds were found at the Schuylkill Trail site in 1997.

Table 2—Species, colony height, sex ratio, seed crop, and Chi Square values for Giant and Japanese knotweed study sites in the Ohio, Susquehanna, and Delaware River watersheds

Watershed location	Knotweed species	Colony height	Seed crop[a]	Viability[b]		Sex ratio	Chi square[c]
				1996	1997		
		m	--------------*Percent*--------------				
Ohio River							
Johnstown	Giant	3.0	90	95	90	F=M	—-
Lumber Road	Giant	4.0	90	100	85	F=M	0.72
St. Michael	Giant	3.0	90	95	75	F=M	7.53*
Staple Bend	Giant	4.0	90	95	90	F<M	0.23
Tunnel Hill	Giant	3.5	90	100	90	F<M	1.89
Susquehanna River							
Archrock	Japanese	3.5	1	0	40	F	14.00*
Bitumen	Giant	4.0	90	90	90	F<M	1.98
Hyner[d]	Japanese	2.7	70	60	80	F<M	7.53*
McElhatten[de]	Hybrid	4.0	90	80	-	F>M	—-
Port Trevorton[e]	Japanese	4.0	90	85	95	F>M	—-
Rothrock	Japanese	3.5	90	85	100	F=M	—-
Sinnemahoning	Giant	4.0	90	-	95	F=M	2.62
Delaware River							
Betzwood Park	Japanese	2.5	1	80	85	F>M	6.97*
Bushkill Church	Japanese	3.3	5	95	85	F>M	3.25
Dingmans Creek	Japanese	3.5	75	90	95	F>M	—-
Freeman Road	Japanese	3.3	1	90	95	F	—-
Schuylkill Tr.	Japanese	2.0	1	65	-	F	—-
Valley View	Japanese	2.5	1	2	10	F	8.20*

[a] Based on a fully developed raceme with about 1,000 seeds. Seed crop values were the same in 1996 and 1997.

[b] Viability was based on visual assessments of seed coat and endosperm.

[c] X^2 cv= 3.84, df= 1. Seed coat condition used as a predictor of viability. Significance is designated by the * symbol.

[d] Mostly the indicated species but the other species or a hybrid of the two species was observed to be in the general vicinity.

[e] Maybe the hybrid of the two species, *F. bohemica*.

The majority of populations in this study had two types of flowers. There were male-fertile (male) and female-fertile (female) flowers on separate plants. Male-fertile flowers were white, had 7-8 long stamens, and a vestigial, small, yellow ovary. The ovaries on male-fertile flowers were presumed nonfunctional because no seeds were produced. Male inflorescence stems pointed upwards. Male flowers were fragrant and had a feathery appearance. Male flowers were bright white, while female flowers were yellow-green. The female flowers had a larger, yellowish ovary with feathery stigmas, and short stamens around the base. The vestigial stamens in female-fertile flowers were presumed non-functional, due to the absence of seed set when male-fertile flowering plants were absent. The female plants were not able to fertilize each other. The inflorescences were arrayed outward or down. Female plants drooped with the weight of abundant, mature seed. Viability tests were not conducted on the two types of flowers to determine if the vestigial (shorter) sex organs were functional. Flower maturation and pollination were not simultaneous in all populations. The sites that were higher in elevation had earlier development of flowers and seeds. The third flower type, hermaphroditic, was found at a few locations. The pistil and stamens were proportionate in size with the stigmas and anthers equal in height. There were occasional breakdowns in dioecy, because seeds were found on male-fertile plants at Sinnemahoning and Staple Bend.

In the field there were instances of achene separation from the perianth prior to dispersal. It was not known if the seed naturally fell out or if it was consumed. Predation by birds may be a factor in rarity of seedling germination and establishment in the wild (Beerling and others 1994). The abscission zone in the pedicel may be prematurely inactivated by the first hard frost, preempting dispersal by wind (Beerling and others 1994). For this reason, the dewinged seed condition was tested in our seed germination trials.

The flowers were pollinated by bees, ants, butterflies, and beetles. Insect damage was seen in some inflorescences where the seed coat was partially eaten and the endosperm gone. It was believed that damage was done by invertebrates. We observed slugs eating Giant knotweed seedling cotyledons in another study (Niewinski 1998).

Tens to thousands of newly germinated seedlings were seen at Bitumen, Dingmans Creek, Lumber Road, Port Trevorton, Rothrock, St. Michael, Sinnemahoning, and Staple Bend. Differences in germination and survival of seedlings were found between these two areas: the ground underneath the clone, and the area beyond the perimeter of the clone. Those seedlings that had germinated under the canopy of the parents and in the leaf litter did not survive. Thousands of seedlings survived to the end of the first growing season. Some were more than 10 centimeters tall. Second-year seedlings of Giant knotweed were discovered at Bitumen and Sinnemahoning in 1997 and at Bitumen, Port Trevorton, and Lumber Road in 1998. These seedlings had completely independent root systems, and had remnant stems from the previous year's growth.

Apparent Viability Assessments

There was little variation in color and size of seeds among populations over the two years. Giant knotweed had slightly larger seeds, about 1 millimeter longer than Japanese knotweed seeds. Seed conditions ranged from firm seed coat with slightly convex sides and a cream endosperm to shrunken seed coats with a depleted or absent endosperm. Like the seed coat, the endosperm was generally convex trigonal. The outer cells were either green or tan. As the endosperm desiccated it turned chalky white. Some seeds were empty shells with brown crystals inside. The cream colored endosperm may hold more favorable seed reserves than the white color. The white colored endosperm appeared to be desiccating, resulting in a slight separation of the embryo from the endosperm. We were not able to test the differences between colors. Seed production in a population was related to the number and proximity of male and female-fertile plants. Endosperm absence was found when no male-fertile plants grew near the study sites.

Viability values for each site, based on the seed coat and endosperm conditions, are given in Table 2. In 1996 and 1997, Betzwood Park, Bitumen, Bushkill Church, Dingmans Creek, Freeman Road, Johnstown, Lumber Road, Port Trevorton, Rothrock, Staple Bend, and Tunnel Hill sites had viability values above 80 percent. Seed sources with the lowest viability (0-40 percent) were Archrock and Valley View. These sites produced endosperm that was only partially developed or absent. Seed coat condition was not the most accurate method of determining potential viability. There may be better methods of assessing endosperm, like water floatation or X-ray analysis.

Germination Trials

The four seed sources chosen had shown high potential viability in the visual assessments. Cold stratification was not necessary to induce germination. Seed samples stored at room temperature germinated within five days when given water.

The overall potential of seeds to germinate was 91 percent. Analysis of Variance (alpha=.05) indicated significant differences in germination due to seed source, seed conditions, and environmental conditions over time. Tukey's HSD mean separation procedures indicated significant differences among treatments. After 30 days storage, Bitumen and Port Trevorton seeds had significantly different germination percentages (96 and 93 percent germination, respectively) than Rothrock and Staple Bend (88 and 86 percent, respectively) (Table 3). After 75 and 120 days, Bitumen seeds germinated at significantly different rates (97 and 98 percent, respectively) than Rothrock (88 and 90 percent) and Staple Bend (88 and 87 percent). Average germination among seed sources and over all seed and environmental conditions were significantly different. The results were Staple Bend 88 percent, Rothrock 89 percent, Port Trevorton 92 percent, and Bitumen 96 percent. The range

Table 3—Mean[a] germination percentages for seed source, seed condition, and environmental condition factors after 30,75, and 120 days storage on Giant and Japanese knotweed seed. N= 11,520 seeds used total

Factors	Storage time (days) 30	75	120	Overall avg.
	Percent			
Seed source (SS)				
Staple Bend (SB)	86.0b	87.4b	86.9c	86.8c
Rothrock (RR)	88.1b	87.6b	90.0bc	88.6c
Port Trevorton (PT)	92.6a	91.8ab	92.8ab	92.4b
Bitumen (BT)	95.7a	96.4a	97.9a	96.7a
Seed condition (SC)				
Natural	89.9a	88.9b	90.0b	89.6b
Dewinged	91.3a	92.7a	93.8a	92.6a
Environmental condition (EC)				
Warm-dry	89.8b	86.7b	89.9b	88.8b
Cold-dry	87.4b	90.5b	89.8b	89.2b
Cold-moist	94.6a	95.2a	96.1a	95.3a
SS * EC				
SB * warm-dry	83.6bc	84.7b	83.8b	84.1c
SB * cold-dry	82.8c	86.6b	82.8b	84.1c
SB * cold-moist	91.6ab	90.9ab	94.1ab	92.2b
RR * warm-dry	85.3bc	80.0b	84.1b	83.1c
RR * cold-dry	80.9c	85.3b	88.8b	85.0c
RR * cold-moist	98.1a	97.5ab	97.2ab	97.6a
PT * warm-dry	95.3ab	88.1b	93.8ab	92.4b
PT * cold-dry	90.3b	94.1ab	90.3ab	91.6b
PT * cold-moist	92.2ab	93.1ab	94.4ab	93.2ab
BT * warm-dry	95.0ab	94.1ab	97.5a	95.5ab
BT * cold-dry	95.6ab	95.9ab	97.5a	96.4ab
BT * cold-moist	96.6ab	99.1a	98.8a	98.1a

[a] Means within a factor (e.g. seed source) and under a storage time with the same lower case letter are not significantly different at the .05 level.

of germination inclusive of sources and different conditions was 60-100 percent.

The dewinged seed condition had significantly different germination percentages after 75 and 120 days storage (93 and 94 percent, respectively) than the natural seed condition (89 and 90 percent) (Table 3). Initially we thought that this might be important, however we found the dewinged seed condition was not a critical factor in nature, because seed rarely dispersed without the wing attached.

The three environmental conditions tested, warm-dry, cold-dry, and cold-moist, were all sufficient for germination (Table 3). Germination increased with time and reached 98 percent for the cold-moist treated seeds after 120 days storage. The cold-moist storage condition simulated Mid-Atlantic winter weather. The overall mean germination percentages for the environmental conditions over storage times were: warm-dry 88 percent, cold dry 90 percent, and cold-moist 95 percent (Table 4). Over the three storage times, germination percentages for seeds stored under cold-moist conditions were significantly different than seeds stored under the warm-dry and cold-dry conditions.

Some of the variability in seed germination was due to a significant interaction between seed source and environmental condition (Figure 2). Staple Bend and Rothrock had one pattern of response, while Port Trevorton and Bitumen had another pattern. The Staple Bend-Rothrock pattern showed statistically significant germination differences between cold-moist and warm-dry/cold-dry conditions. For the Port Trevorton-Bitumen pattern the differences among treatments could not be separated out. The patterns were not attributed to species differences because seeds collected from Staple Bend and Bitumen were Giant knotweed, while those from Rothrock

Table 4—Overall mean[a] percent seed germination for storage times and environmental conditions among all seed sources and seed conditions. N = 3,840 seeds used per storage time

	Storage time (days)			
Environmental conditions	30	75	120	Overall
	Percent			
Warm dry	88b	88b	90b	88b
Cold dry	88b	90b	90b	90b
Cold moist	95a	95a	98a	95a

[a] Values within each storage time with the same lower case letter were not significantly different at the .05 level.

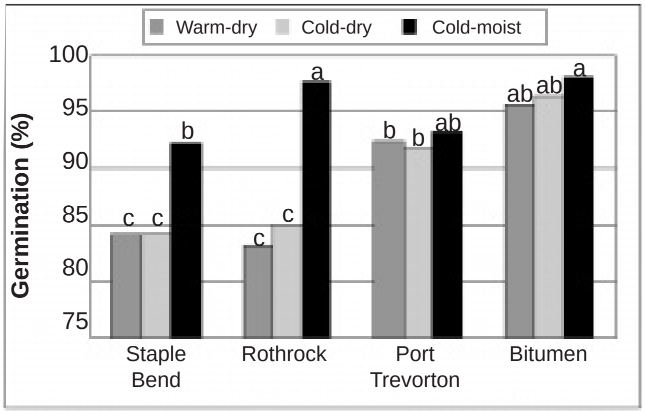

Figure 2—Overall mean percent germination for Giant and Japanese knotweed seed under three environmental conditions. N= 960 seeds per source under each environmental condition. Values among all seed sources and storage times with the same lower case letter are not significantly different at the .05 level.

and Port Trevorton were Japanese knotweed. Since collection was done in October, all seed had similar maturity. The plants growing at Bitumen produced seed with the highest percent germination under the cold-moist storage conditions.

Although germination varied due to a few factors, overall percentages were high. The different combinations we tested provided valuable evidence that Japanese and Giant knotweed were capable of reproducing sexually in the United States.

Viability Assessment Germination Trials

Seeds with shrunken seed coats were believed to be those in which the endosperm had not been fully developed. The null hypothesis was that seed coat condition, normal or shrunken, made no difference in germination. Chi Square analysis (alpha=.05, df=1, critical value = 3.84) indicated significant differences in germination percentages for these five sources: St. Michael, Archrock, Hyner, Betzwood Park, and Valley View (Table 2). The null hypothesis was rejected for these seed sources, because seed coat condition did make a difference in germination. Seeds with shrunken seed coats had significantly lower germination percentages. Germination percentages for Lumber Road, Staple Bend, Tunnelhill, Bitumen, Sinnemahoning, and Bushkill Church were not significantly different between normal and shrunken seed coat conditions. The null hypothesis was not rejected for these six seed sources.

Half of the seeds performed as expected, in that seeds with the shrunken coat condition did not germinate. However, some shrunken seeds germinated at high percentages. The explanation is probably linked to the population structure and the relative proportion of plants of different sexes. A common factor among the sources that performed as expected was the ratio of female:male plants. Japanese knotweed plants at Hyner, Valley View, Archrock, and Betzwood Park exhibited shrunken seed coats and all had mostly female or only female parent plants. Bushkill Church had more female Japanese knotweed plants than male. The remainder of the sites had Giant knotweed, of these, Staple Bend, Tunnelhill, and Bitumen, had a greater proportion of male plants. Lumber Road and Sinnemahoning had equal numbers of male and female plants. The abundance of male plants was integral, because of increased chances of pollination. Seed coat condition was not a consistently good descriptor of seed quality, and other methods should be explored.

Soil Core Study

Soil cores were placed into a greenhouse on May 20. Germination of the knotweed seeds began May 27 and culminated on July 2. The mean number of seedlings per core by June 21 were Bitumen 4, Lumber Road 24, Rothrock 32, and Staple Bend 5. The mean number of potential seedlings per square meter were extrapolated from this data (Figure 3). The range of seedlings in the cores was 0-120, or equivalent to greater than 6,500 seedlings per square meter). Analysis of Variance (alpha=.05) showed that the mean number of seedlings from soil samples taken at Rothrock and Lumber were significantly different than those from Staple Bend and

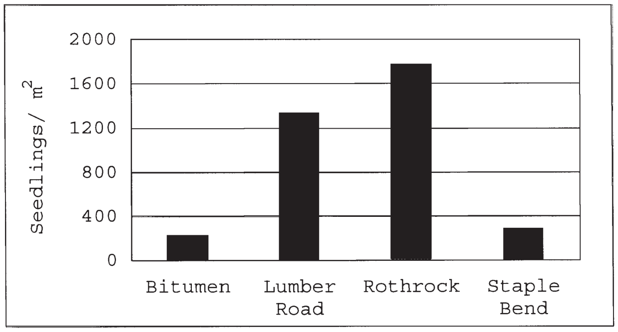

Figure 3—Mean number of potential seedlings/ m^2 at the four study sites, extrapolated from the number of seedlings per 182 cm^2 soil core. N= 50 cores per soil source.

Bitumen. There were no significant differences between Staple Bend and Bitumen or between Rothrock and Lumber Road (Table 5).

The majority of seedlings emerged from the sides of the core, where the soil profile had been slightly disturbed during collection and placement. The soil was not mixed to promote germination.

The results of Bitumen cores were lower than expected, based on the viability assessments and germination data. This may be attributed to the difficulty of collecting an intact soil core. Gravel in the strip-mine spoil made it nearly impossible to get an intact soil core close to the knotweed. The low number of seedlings could be due to a reduced amount of soil collected, or to increased distance from parent plants.

Rothrock soil cores had significantly different numbers of seedlings than those from Staple Bend, although there were no significant difference in germination potentials for the two sources of seed. Soil quality and abundance of seed-eating invertebrates may be contributing factors to the differences in number of seedlings emerging from the soil cores. Staple Bend and Rothrock soil cores had thick humus layers, while Bitumen and Lumber Road cores had little humus and came from gravel road areas.

There was a naturally occurring, viable seedbank at these four locations. Seedling mortality was expected because of the reported absence of seedlings in nature. However, the soil core study showed that seedlings were capable of surviving and producing flowers and seeds within one growing season.

CONCLUSIONS

Japanese and Giant knotweed were found throughout three river drainages in Pennsylvania. The populations examined were the dominant vegetation on the sites. Millions of seed were produced annually by Japanese and Giant knotweed at these locations. Independent, multiple year seedlings were discovered at four locations in the summer of 1996 and 1997.

The use of physical characteristics to determine viability was not reliable. Seed coat condition was not a consistently good indicator of seed quality. The potential of Japanese and Giant knotweed seed to germinate depended on the viability of the endosperm. Endosperm content can be visually assessed for a rough estimate of viability. A germination test is the best method for determining the sexual reproduction of a population.

The germination trials showed that Mid-Atlantic winter weather conditions were the best for seed germination. Cold-moist storage of seeds over 30, 75, and 120 days yielded the highest percent germination, averaging 95 percent overall. The mean percent germination for the four seed sources over all storage times, seed conditions and environmental conditions was 91 percent.

Seedbanks were found to be naturally occurring at four of the study sites and had the capacity to germinate in the spring and summer. Seeds in soil can go into induced dormancy and germinate under more favorable conditions, like when exposed to air after soil disturbance. Seedlings have the capacity to survive and grow into vegetative adults in one growing season. Observations during the seedbank study suggested that soil disturbance might lead to higher incidences of seedling emergence.

Japanese and Giant knotweed pose serious threats to our natural ecosystems and should be managed carefully. Seeds germinate in the spring and summer. Areas should be monitored for seedlings, especially in riparian zones and on paths where bare soil is exposed.

Table 5—Mean[a] number of Giant and Japanese knotweed seedlings/ core, range of seedlings/core, and number of potential seedlings per m^2 from four soil sources. N = 50 cores per soil source

Soil source	Seedlings	Range	Seedlings
	-------- *Per core* --------		*Per m^2*
Bitumen	4b	0-37	220
Lumber Road	24a	0-120	1319
Rothrock	32a	0-106	1758
Staple Bend	5b	0-28	275

[a] Values of seedlings per core among the soil sources with the same lower case letter were not significantly different at the .05 level.

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