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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REFERENCES

Bowersox, T.W.; Ahlswede, L.M.; Smith, J.L. [In press]. A model to inventory reproduction and predict regeneration success in mixed oak stands of central Pennsylvania. University Park, PA: Agricultural Research Station, Pennsylvania State University.

Brister, G.H.; Schultz, R.C. 1981. The response of a Southern Appalachian forest to waste water irrigation. Journal of Environmental Quality. 10: 148-153.

Epstein, C.M.; Sawhill, G. 1977. Changes in the ground cover of a New Jersey pine barrens woodland resulting from spray irrigation of sewage effluent. Bulletin New Jersey Acad. Sci. 22: 6-11.

Kennedy, Jr., H.E. 1990. *Fraxinus pennsylvanica* Marsh. Green ash. In: Silvics of North America. Agric. Handb. 654. U.S. Department of Agriculture, Forest Service: 348-354. Vol. 2.

Larrick, D.S.; Bowersox, T.W. 1999. Long-term effects of wastewater irrigation on forested ecosystems at Pennsylvania State Game Lands 176. In: Proceedings, 12th central hardwood conference. Gen. Tech. Rep. SRS-24. U.S. Department of Agriculture, Forest Service: 90-97.

Lull, H.W. 1968. A forest atlas of the northeast. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 46 p.

Marquis, D.A.; Ernst, R.L; Stout, S.L. 1992. Prescribing silvicultural treatments in hardwood stands of the Alleghenies. Revised. Gen. Tech. Rep. NE-96. U.S. Department of Agriculture, Forest Service. 102 p.

McQuilkin, R.A. 1990. *Quercus palustris* Muenchh. Pin oak. In: Silvics of North America. Agric. Handb. 654. U.S. Department of Agriculture, Forest Service: 709-714. Vol. 2.

Perala, D.A. 1990. *Populus tremuloides* Michx. Quaking aspen. In: Silvics of North America. U.S. Department of Agriculture, Forest Service: 555-569. Vol. 2.

Sanders, I.L. 1990. *Quercus rubra* L. Northern red oak. In: Silvics of North America. Agric. Handb. 654. U.S. Department of Agriculture, Forest Service: 727-733. Vol. 2.

Sopper, W.E.; Kardos L.T., eds. 1973. Recycling treated municipal wastewater and sludge through forest and cropland. University Park, PA: The Pennsylvania State University Press. 479 p.

Storm, G.L. 1995. Wildlife investigations. In: 1995 forecast of loading report. University Park, PA: Office of Physical Plants, the Pennsylvania State University: 501-529.