# EFFECTS OF CANOPY AND HERBACEOUS COVERAGE ON REGERERATION IN A FOREST COMMUNITY IRRIGATED WITH TREATED WASTEWATER IN CENTRAL PENNSLYVANIA

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ABSTRACT.—Forest communities on Pennsylvania State Gamelands 176 (Toftrees) have been irrigated weekly with 5 cm of treated municipal wastewater since 1983. The understory of the irrigated forest communities was dominated by herbaceous vegetation and lacked tree regeneration. Our objective was to determine the effect of the existing canopy coverage and understory vegetation on natural and artificial regeneration.

Canopy coverage and the presence of herbaceous vegetation did not affect establishment of natural regeneration. After two growing seasons, the density of seedlings from natural regeneration was <1 seedling $m^{-2}$. However, artificial regeneration did respond to canopy treatments. Planted seedlings of five tree species had the greatest survival and height growth on open canopy treatments. Removal of herbaceous vegetation also improved the survival of artificial regeneration.

The results of this study determined that natural regeneration did not occur in sufficient numbers within the irrigated forest community. However, artificial regeneration can be used to augment these numbers. Creation of small, open canopy areas within the existing irrigated forest communities, treatment of the understory with herbicide, and planting a selection of species capable of growing under the irrigation conditions will ensure a future forest community.

## Introduction

The Pennsylvania State University has been irrigating its treated municipal wastewater onto forest and agricultural land since 1983. The existence of a healthy forest community has become important to the success of a year-round wastewater application program, especially in the winter months when agricultural soils tend to freeze. Five cm of treated wastewater have been irrigated weekly onto forest and agricultural lands at Pennsylvania State Gamelands 176 (Toftrees). During this period of irrigation, an alteration of species composition and forest stand structure had occurred. The irrigated forest communities had low overstory and understory densities, lacked regeneration of tree species, and the understory was dominated by herbaceous plants, indicating that the natural regeneration processes were not occurring (Larrick and Bowersox 1999).

As trees die in a forest community, small openings, or gaps, in the canopy are created. Windstorms also create larger gaps by blowing down one or more adjacent canopy trees. When the surrounding trees do not fill the gaps in the canopy, the understory plants become the beneficiaries of light, water, nutrients, and growing space, thus starting the gap-phase stage of stand development (Watt 1947, Bormann and Likens 1979, Hibbs 1982). In most forest communities, established tree seedlings and saplings (advanced regeneration) captured the increased resources within the gap and increased their growth (Oliver and Larson 1996). However, the irrigated forest community lacked this gap-phase dynamic. Advanced regeneration was not established so that when gaps were created, herbaceous vegetation captured the resources and dominated the site. The objective of this study was to determine the effect of the existing canopy and understory herbaceous vegetation on natural regeneration processes. In

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addition, seedlings were planted to determine species survival and growth under the growth the irrigated conditions.

## Study Areas

The study site was located on Pennsylvania State Gamelands 176 (Toftrees), approximately 2 km north of University Park, PA. The Toftrees area was leased by the university from the Pennsylvania Game Commission in 1983 to expand its municipal wastewater irrigation system. The Toftrees area is located in the Ridge and Valley region of central Pennsylvania (Lull 1968). The average annual precipitation is 95 cm (Braker 1981). Site quality was average, and if occupied by an even-aged mixed oak stand, the site index would be 20 m at 50 years (Larrick and Bowersox 1999). Soils present on the site were primarily Morrison (Ultic, Hapludalf) and Hagerstown (Typic, Hapludalf).

## Materials and Methods

Twelve 0.20 ha circular plots were located in the irrigated forest communities. The DBH and species of the overstory trees were recorded. Three canopy treatments were randomly assigned to each of the plots (four replicates per canopy treatment). The canopy treatments were closed canopy, partial canopy, and open canopy. Closed canopy treatment plots had no overstory trees removed; partial canopy treatment plots had enough overstory trees removed to obtain a 70-75% stocking level; and the open canopy treatments had all overstory trees removed. Canopy treatments occurred in April 2000.

Within each 0.20 ha canopy treatment plot, four 10 x 10 m understory treatment plots were established. Each subplot was assigned one of two understory treatments (herbicide, control). Two plots were treated with herbicide and two were untreated. The herbicide treatment was 2% glyphosate applied in May. The understory subplots were enclosed with wire fencing (2 m in height) to exclude white-tailed deer (*Odocoileus virginianus*) foraging on the vegetation.

In May 2000, five species were planted as seedlings within each of the understory treatment plots. The species included quaking aspen (*Populus tremuloides* Michx.), red maple (*Acer rubrum* L.), black gum (*Nyssa sylvatica* Marsh.), river birch (*Betula nigra* L.), and Norway spruce (*Picea abies* (L.) Karst.). A total of 1,440 seedlings were planted (six seedlings per species per understory treatment plot). Height growth of seedlings was recorded in August.

Natural regeneration was monitored on three 2 x 2 m areas within each understory treatment plot. Seedlings were inventoried in August by species and size. Also, the percent ground cover and aboveground biomass of herbaceous vegetation were inventoried on the understory plots not treated with herbicide.

Soil samples were collected from each understory treatment plot in October. The samples were sent to the Pennsylvania State University Agricultural Analytical Laboratory for analysis. The samples were analyzed for pH, phosphorus, cation exchange capacity (CEC), the base saturation of potassium, magnesium, and calcium, total nitrogen, and nitrate-nitrogen. Measurements of all variables were taken for two growing seasons (2000 and 2001), however, only the findings of the second growing season are presented for brevity.

### Statistical Analysis

Analysis of variance (ANOVA) was used to determine if significant differences existed among canopy treatments for mean basal area and density before and after canopy treatments. The effects of canopy and understory treatments and their interaction on height growth of the artificial regeneration were also determined using ANOVA. Main effects and interactions were significant at the $p<0.05$ level. Tukey's mean separations were used to determine differences among treatments and were significant at the $p<0.05$ level.

Survival of artificial regeneration was modeled using binary logistic regression. The independent variables included species, and canopy and understory treatments. Model I included the variable

**Table 1.—Mean tree density and basal area before (Fall 1999) and after (Spring 2000) canopy removal treatments on Pennsylvania State Gamelands 176 (Toftrees).**

| | Density trees $ha^{-1}$ | | Basal Area $m^2ha^{-1}$ | |
|---|---|---|---|---|
| | *Before* | *After* | *Before* | *After* |
| Closed canopy | 366 ab | 366 a | 22 ab | 22 a |
| Partial canopy | 374 a | 293 b | 24 a | 18 b |
| Open canopy | 326 b | 0 c | 18 b | 0 c |

species. Model II also included canopy treatment. Model III included all three variables of species, canopy and understory treatments. The dependent variable was survival (0=dead; 1=alive). Each independent variable had a reference or control. Quaking aspen was the reference for species because it had been studied within the irrigated community (Jacobs 1997, Kelso 1999). Closed canopy was used as the reference for canopy treatment because it reflected the current conditions of the irrigated forest community. Similarly, plots not treated with herbicide were used as a reference because of the exiting herbaceous vegetation that dominated the understory.

## Results

Prior to tree removal, the mean stem density and basal area of the canopy treatment plots was similar (table 1). The partial canopy treatment had the greatest stem density with 374 trees $ha^{-1}$, but was not significantly different from the closed (366 trees $ha^{-1}$) or the open canopy treatments (326 trees $ha^{-1}$). The partial canopy treatment plots had a greater mean basal area prior to treatment with 24 $m^2$ $ha^{-1}$, and was not significantly different from the closed canopy (22 $m^2$ $ha^{-1}$). The open canopy treatment plots had the least amount of basal area with 18 $m^2$ $ha^{-1}$ and were significantly different from the partial canopy treatments, but not the closed canopy treatments.

Following overstory tree removal, there were significant differences in the mean stem density and basal area among canopy treatments (table 1). The stem density and basal area of the closed canopy treatments remained the same, whereas the stem density of partial canopy treatment plots was reduced to a mean of 293 trees $ha^{-1}$ and the open canopy had no trees remaining on these plots. The average basal area of the partial canopy plots was reduced by 6 $m^2$ $ha^{-1}$ to 18 $m^2$ $ha^{-1}$, and the open canopy had a basal area of zero.

Mean relative density of the irrigated forest after canopy treatments was represented by the species of the white oak group [(white oak (*Quercus alba* L.), chestnut oak (*Quercus prinus* L.)] at 37 percent, red maple and the species of the red oak group [northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam., and scarlet oak (*Quercus coccinea* Muenchh.)] both at 25 percent. All other species [including quaking aspen, black cherry (*Prunus serotina* Ehrh.), and eastern white pine (*Pinus strobus* L.)] each represented less than 4 percent of the relative density.

**Table 2.—Mean ground coverage aboveground herbaceous biomass during the second (2001) growing seasons by canopy treatment on Pennsylvania State Gamelands 176 (Toftrees).**

| | Ground Coverage percent | Biomass g $m^{-2}$ |
|---|---|---|
| Closed canopy | 60 c | 80 c |
| Partial canopy | 79 b | 139 b |
| Open canopy | 100 a | 496 a |

Overall the number of stems recorded on the natural regeneration plots was very low and we were unable to perform a statistical analysis. The number of tree stems recorded was 194 across all natural regeneration subplots (<1 seedling $m^{-2}$). Eighty percent of the recorded seedlings were on understory plots that were treated with herbicide, and 75 percent of the seedlings were recorded on the open canopy treatment plots. Red maple was the most abundant species, followed by black cherry. However, all inventoried seedlings were less than 25 cm in height.

The ground coverage and aboveground herbaceous biomass were significantly different among the three canopy treatments (table 2). Mean ground coverage on closed canopy treatments was 60 percent. On

**Table 3.—Logistic regression models[1] for the survival of planted seedlings after the second growing season (2001) on Pennsylvania State Gamelands 176 (Toftrees).**

| Dependent Variable: Alive =1; Dead=0 | Model I | | Model II | | Model III | |
|---|---|---|---|---|---|---|
| | *b* | $e^b$ | *b* | $e^b$ | *b* | $e^b$ |
| Species (reference=quaking aspen) | | | | | | |
| Red maple | 0.6* | 1.9 | 0.9* | 2.4 | 1.0* | 2.8 |
| Black gum | -0.1* | 0.9 | 0.1 | 1.1 | 0.2 | 1.2 |
| River birch | -1.4* | 0.2 | -1.3* | 0.3 | -1.3* | 0.2 |
| Norway spruce | 2.2* | 8.9 | 2.5* | 12.1 | 2.7* | 14.1 |
| Canopy (reference=closed) | | | | | | |
| Partial | | | 0.5* | 1.6 | 0.5* | 1.7 |
| Open | | | 1.5* | 4.3 | 1.6* | 4.9 |
| Understory (reference=no herbicide) | | | | | | |
| Herbicide | | | | | 1.3* | 3.6 |
| Intercept | 0.5* | | -0.4 | | -1.2* | |
| -2 Log likelihood (d.f.) | 1,113 (4) | | 1,050 (6) | | 938 (7) | |
| Model Chi-square (d.f.) | | | 63 (2)* | | 67 (1)* | |

[1]Coefficients designated by (b) and odds ratio by ($e^b$).

partial canopy treatment plots mean ground coverage was 79 percent. The open canopy treatments had the greatest mean ground coverage, 100 percent. The open canopy treatment plots had a mean aboveground biomass of 496 g $m^{-2}$, which was 3.5 times greater than the mean biomass produced on the partial canopy treatments (139 g $m^{-2}$), and 6 times greater than the closed canopy treatment plots (80 g $m^{-2}$).

A total of 691 seedlings were alive at the end of the second growing season. Seedling survival at the end of the second growing season was greatest on the open canopy plots and the herbicide subplots for all species planted. Model I demonstrated the relationship between seedling survival and species (table 3). Survival of all four species was significantly different from the quaking aspen seedlings. Seedlings of red maple and Norway spruce were more likely to survive than the quaking aspen. Black gum and river birch seedlings had lower survival than quaking aspen seedlings.

In Model II, the addition of the independent variable of canopy treatment changed the species analysis. Black gum seedling survival was no longer significantly different from quaking aspen seedling survival, and the coefficient became positive. Black gum seedling survival was greater than quaking aspen seedlings on two of three canopy treatment plots, which accounted for the change in signs of the coefficient. The open canopy treatment plots had seedling survival 4.3 times greater than the closed canopy. Seedlings on the partial canopy plots were 1.6 times more likely to survive than seedlings on closed canopy plots. The addition of understory to the Model III did not change the significance of the other independent variables, and was significant. The use of herbicides increased seedling survival by a factor of 3.6.

At the end of the second growing season, a response to canopy treatment was observed for all planted species (table 4). Some of the seedlings experienced dieback from the terminal bud, which accounted for negative height growth. Quaking aspen seedlings on the open canopy treatment plots had a mean height growth of 117 cm, which was significantly different from seedlings on the partial (31 cm) and the closed (17 cm) canopy treatments. River birch seedlings had the second greatest mean height growth on the open canopy plots with 41 cm and was significantly different from seedling height growth on the closed canopy (-19 cm) treatment plots, but not from the partial canopy (-3 cm) treatments. Seedlings of red maple and black gum were similar in their height growth responses to the canopy treatments. Both species had the greatest response on the open canopy treatments, a slight height growth response on the partial canopy treatments, and negative height growth on the closed

**Table 4.—Mean height growth (cm) of planted seedlings by species, canopy and understory treatment after the second growing season (2001) on Pennsylvania State Gamelands 176 (Toftrees).**

| | Quaking aspen | Red maple | Black gum | River birch | Norway spruce |
|---|---|---|---|---|---|
| Canopy | | | | | |
| Closed | 17 b | 5 b | -2 b | 19 b | 0 b |
| Partial | 31 b | 2 b | 1 b | 3 ab | 5 b |
| Open | 116 a | 28 a | 17 a | 41 a | 11 a |
| Understory | | | | | |
| No Herbicide | 64 a | 7 a | 5 a | 1 a | 6 a |
| Herbicide | 72 a | 10 a | 7 a | 17 a | 5 a |

**Table 5.—Mean values for soil variable based on canopy treatment for the second growing season (2001) on Pennsylvania State Gamelands 176 (Toftrees).**

| | pH | P | CEC | K | Mg | Ca | Total-N | Nitrate-N |
|---|---|---|---|---|---|---|---|---|
| | | $g\ m^{-2}$ | meq 100 $g^{-1}$ | percent saturation | | | percent | ppm |
| Canopy | | | | | | | | |
| Closed | 7.5 a | 39.8 ab | 20.7 a | 1.4 b | 28.8 a | 69.8 a | 0.48 a | 51.4 a |
| Partial | 7.4 ab | 38.1 b | 17.6 b | 1.4 b | 27.4 a | 71.2 a | 0.32 b | 34.6 b |
| Open | 7.6 a | 49.1 a | 20.8 a | 2.4 a | 29.4 a | 68.2 a | 0.52 a | 60.7 a |

canopy treatments. Red maple seedlings had a mean height growth of 28 cm on the open canopy and were significantly different from the partial (2 cm) and closed canopy (-5 cm) treatment plots. Black gum seedlings had 17 cm of height growth in the open canopy and were significantly different from the partial (1 cm) and open (-2 cm) canopy treatment plots. Finally, Norway spruce seedlings had the lowest mean response on the open canopy treatment (11 cm), and was significantly different from seedlings on the partial (5 cm) and closed (0 cm) canopy treatments. After the second growing season, there was no significant difference in the response of planted seedlings to understory treatments or to the interaction of canopy by understory interaction.

Soil analysis demonstrated the high nutrient content of the irrigated soils (table 5). During the second growing season, there were significant differences among canopy treatments for six of the eight measured soil variables. The partial canopy treatment plots had mean soil variables that were significantly different from the closed and open canopy treatment plots. In all cases where there was a significant difference for the tested variable, the partial canopy treatment plots had the lowest mean value. The soil pH values for the irrigated soils ranged between 7.4-7.6 and the base saturation was 100 on the canopy treatment plots.

## Discussion

The ability of the Pennsylvania State University to irrigate its treated municipal wastewater year-round depended on the existence a forest community. However, the future of the forest community on State Gamelands 176 (Toftrees) was not certain. The yearlong application of 5 cm of treated wastewater to the existing forest community had altered the structure of the forest community, replacing woody species in the understory with herbaceous vegetation. The forest community has entered the gap-phase stage of stand development, but few tree stems have been established to replace the overstory. The low stem density of tree seedlings inventoried across all treatments indicated that a herbaceous community eventually would replace these stands.

The negligible number of tree stems inventoried on all treatments indicated that there was a failure in the natural regeneration process (seed production, storage, and germination, and seedling establishment). The necessary conditions for seedling establishment were provided for most tree species found in the overstory. For example, the optimal conditions for quaking aspen germination were full sunlight and bare mineral seedbed (Perala 1990), which were represented on the open canopy/herbicide subplots. However, no quaking aspen seedlings were inventoried as natural regeneration. The germination requirements for black cherry were also provided (partial or closed canopy and undisturbed leaf litter) (Marquis 1990) and a few stems were inventoried, but none were established seedlings. Acorns of oak species have greater rates of germination when they have been stored in the soil or covered with a layer of litter (Auchmoody et al. 1994, Lhotka and Zaczek 2002). These conditions were established and again a few stems were inventoried, but none were established seedlings. The exact cause of the failure of natural regeneration has not yet been determined. Removal of the canopy and herbaceous understory did not produce natural regeneration of tree species in sufficient numbers.

The influence of canopy gaps on natural regeneration has been identified as an important mechanism in the regeneration process, as gaps provide increased light, water, and nutrients to stems in the understory. However, some researchers have demonstrated that other factors in addition to canopy gaps influence the regeneration process. Breckage et al. (2000) reported canopy gaps (0.03 ha) made in a southern Appalachian forest did not promote seedlings recruitment, and that disturbance to the forest floor and the presence of understory vegetation were more important factors for seedling recruitment.

The size of canopy gaps has also been investigated. Hibbs (1982) reported larger canopy openings in a hemlock-hardwood forest in Massachusetts favored shade intolerants, whereas medium openings favored shade tolerant species. The results of this study did not demonstrate any differences between the open and partially open canopy treatments for the recruitment of species dependent on shade tolerance.

Planted seedlings of certain species survived and grew under the irrigated conditions. Differences in planted seedling survival among species were attributed to two factors: tolerance of shade and quality of planting stock. Quaking aspen and river birch were species intolerant of shade and, therefore, had low survival on the closed and partial canopy treatments. Conversely red maple, black gum, and Norway spruce were classified as either intermediate or tolerant of shade, and had higher survival rates on all canopy treatment plots. The low survival of both quaking aspen and river birch seedlings was also attributed to inferior planting stock of these species. Seedlings of quaking aspen had very small aboveground stems and the root systems of the river birch were insufficient to support their large aboveground stems. Survival of quaking aspen was similar to previous studies.

Height growth of red maple, black gum, and Norway spruce seedlings did not respond to the canopy treatments in the first growing season. These seedlings depended on their root-reserves and were unresponsive to canopy treatment. In comparison, the height growth of quaking aspen and river birch seedlings was immediately responsive to the high light conditions on the open canopy treatment plots. By the end of the second growing season, all planted tree species had their greatest height growth on the open canopy treatment plots, indicating that full-sunlight was an important factor in seedling growth. Two-year height growth of quaking aspen seedlings was similar to other studies that I have completed on the irrigated forest communities (Ahlswede et al. 1999, Kelso 1999).

The soil analysis of the irrigated forest community was consistent with what other researchers have reported (Larrick and Bowersox 1999). The soil pH reflected the high amount of the base cations present in the irrigated soil. Positively charged base cations replaced hydrogen ions on binding sites in the soil matrix and increased the soil pH. The elevated values of the soil nutrients on the irrigated forest may be the cause for the failure of natural regeneration. The tree species on the irrigated forest communities have been adapted to low soil nutrients and the irrigated conditions were not suitable for the regeneration process for these species.

Creation of small canopy openings in the overstory and application of herbicide did not establish natural regeneration in adequate numbers to produce a fully-stocked forest community. The addition of seedlings from artificial regeneration can be used to supplement natural regeneration. Open canopy treatment plots would not only promote the greatest height growth of planted seedlings, but also aboveground herbaceous biomass production. A partial canopy removal treatment would temper the growth of both artificial regeneration and aboveground herbaceous community. Application of herbicides gives managers the opportunity to create open canopy conditions, which allow maximum growth for all planted species, and at the same time reduce the herbaceous vegetation.

Winter irrigation of the forest community has become imperative to wastewater application. However, winter application has the negative effect of causing damage to small diameter stems from ice accumulation. A management goal has to include protection of any young, woody stems from winter irrigation when the temperatures are below freezing until they have reached a height and diameter to withstand the accumulation of ice.

An important implication of this research was the response of an upland forest community to human disturbance, specifically the addition of highly nutritious wastewater over a short period of time. Future research may be directed at investigating the response of species to changes in the environmental variables (precipitation, edaphic conditions) under which they evolved. Some scientists have predicted that global climate change will affect many ecological regions in the future. The upland forest community on the study site, which had adapted to the climate of central Pennsylvania for centuries, was changed over a short period of time. The response of the forest community has not been positive. Regeneration has not been occurring on the irrigated forest community and herbaceous vegetation has become dominant in the understory. Artificial regeneration continues to be an alternative to establishing a forest community on State Gamelands 176 (Toftrees).

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