Competition of Tree Species in Resonse to Chronic Nitrogen Loading in a Northern Hardwood Forest

Kyle T. Schwabenbauer
Allegheny College, Meadville, Pennsylvania 16335 USA

Abstract

We studied the effects of chronic nitrogen additions, through sewage wastewater irrigation, on forest succession on Cape Cod, Massachusetts. We hypothesized that forest conditions created by wastewater irrigation would increase the rate of forest succession and possibly favor specific tree species. Our study site was the Falmouth Sewage Treatment Plant, which has been irrigating a 24-ha area of northern hardwood forest since 1988. We established six plots in the irrigation area: two with high densities of pitch pine, two with high densities of black oak, and two with high densities of white oak. Six control plots were also established that received no wastewater irrigation. We collected tree cores from three trees of each species in each plot. We calculated biomass and annual growth of each tree by measuring the growth increments for each year during the last 20 years. We found that pitch pines showed the greatest and most rapid increase in growth in all plots when irrigated with sewage wastewater. However, irrigation did not appear to change the natural species succession of the forest, as stand characteristics naturally began to favor growth of white oaks. Our study showed that in all plots where white oaks were present, white oaks increased their biomass more overall than that of pitch pines and black oaks. This suggests that white oaks are more likely to dominate both irrigated and unirrigated forests in the future.

Keywords: forest, wastewater; irrigation; succession; nitrogen; species competition; pitch pine; black oak, white oak.

Introduction

Chronic nitrogen loading can have dramatic effects on soil properties, plant growth, and species composition of forested ecosystems (Jordan et al. 1997). In most terrestrial ecosystems, nitrogen is a limiting nutrient for plant growth and can stimulate increases in primary production (Aber et al. 1989). As a result, it has been suggested that forests could be used to remove excess nitrogen from sewage wastewater (Cole et al. 1986). This strategy may present a problem because irrigating forests with sewage wastewater not only adds nitrogen, but also a great deal of water to the soil. Together, these inputs may change the way plant species compete for resources and may favor species that are not usually abundant in natural forests. In this study, we examined the effects that irrigation and nitrogen fertilization can have on growth rates and tree species succession of a northern hardwood forest on Cape Cod.

Our research was conducted at the Falmouth Sewage Treatment Plant (FSTP) in

Massachusetts. Since 1988, the plant has been disposing of its treated wastewater with spray irrigation techniques over a 24-ha area of forest. In earlier experiments, we noticed that in areas receiving no irrigation, black oaks had much greater basal areas than pines or white oaks (Fig. 1). However, in irrigated plots, basal areas were much more uniform across tree species. We also discovered that black oaks had higher growth rates than that of white oaks in areas that were not irrigated (Fig. 2).

Therefore, we hypothesized that the experimental sewage irrigation plan will increase basal area and overall biomass of white oaks in relation to black oaks and pitch pine trees. Additionally, we predicted that growth rates and net primary production (NPP) of white oaks would increase in relation to that of pitch pines and black oaks. This could potentially increase the rate of forest succession to favor "older forest" white oaks and other hardwoods over the "younger forest" black oaks and pitch pines. Consequently, the residence time of tree species may be reduced and the rate of forest succession could increase.

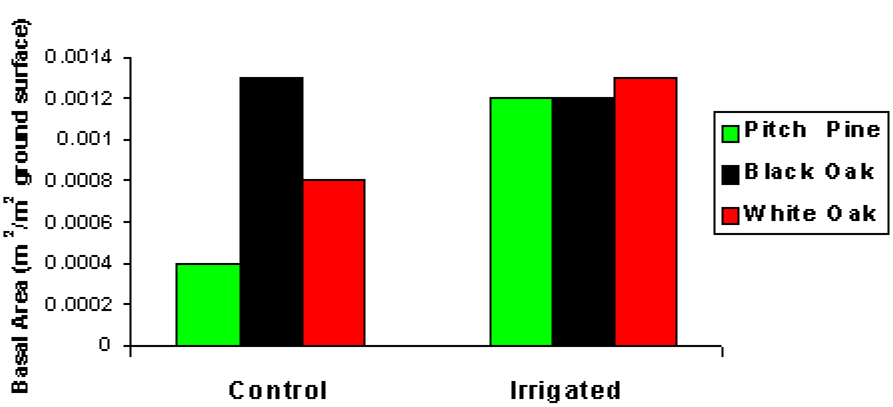

Figure 1. Basal Area Across Treatment.

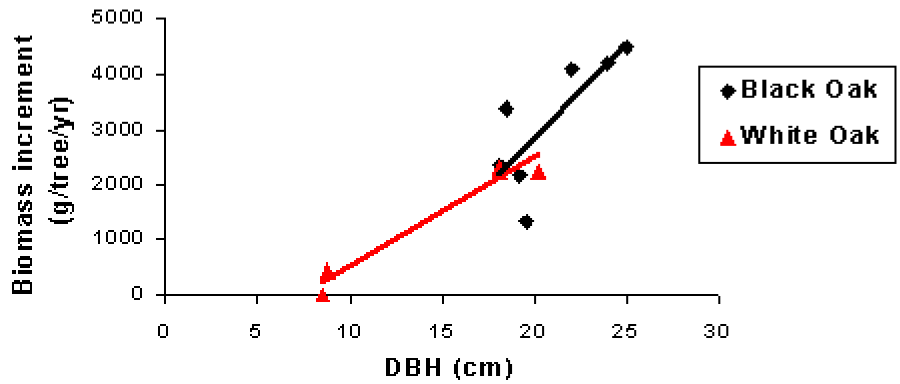

Figure 2. Natural Growth Rates of Oaks.

Methods

We established six plots in areas receiving wastewater irrigation: two with high densities of pitch pine, two with high densities of black oak, and two with high densities of white oak. Six similar plots were also selected as controls and received no irrigation. Our plots were circular, and their size (12-15 m in diameter) was dependent on tree density. Each plot contained 10-20 trees of the dominant species in the plot. We collected complete tree cores from three trees of each studied species in each plot in order to determine the age and growth rate of each tree. Cores of black oaks and white oaks were not collected in pitch pine plots because of the small numbers of oaks growing there. We determined annual growth of each tree by measuring the growth increments for each year during the last 20 years. All of our cored trees were at least 20 years old, so we were able to obtain growth increments for the last 20 years in all plots. We also measured diameter at breast height (DBH) of every tree in each plot in order to calculate the basal area and total biomass of each tree in the plots. We estimated total tree biomass using allometric regressions based on DBH measurements (Whittaker & Woodwell 1968). We also tested for statistical significance between treatments and species using a two-factor analysis of variance (ANOVA) with replication.

We also obtained mean temperature and precipitation data during the growing season since 1979 to compare to possible tree growth responses in control plots. Because of time constraints and data available to us at this time, we have focused on tree growth rates and not studied other aspects of forest succession. A full analysis of succession would obviously need to include analysis of reproductive success of tree species.

Results

We found that biomass distribution of each tree species per tree was very similar in irrigated and control plots (Fig. 3 & 4). In all plots, the biomass was reflective of natural forest succession, with pitch pines being the oldest trees and having the greatest biomass, followed by black oaks and white oaks respectively. Similarly, the oldest and largest trees were found in white oak plots, followed by black oak plots and then pitch pine plots.

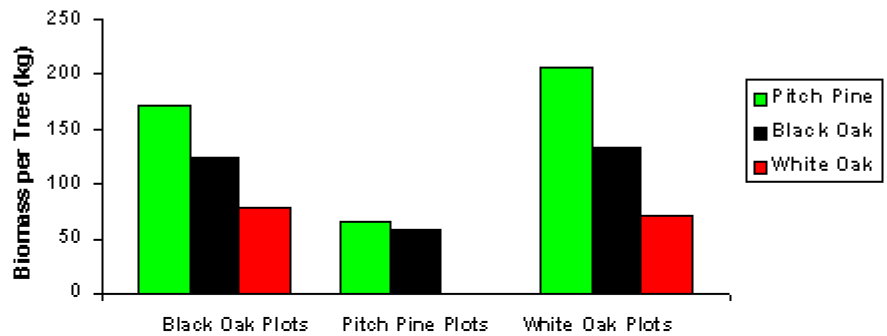

Figure 3. Biomass distribution of tree species in control plots.

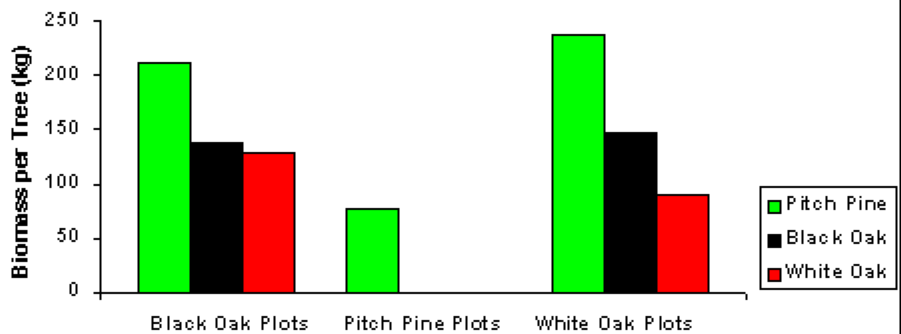

Figure 4. Biomass distribution of tree species in irrigated plots.

When irrigation began, pitch pines showed the largest increase in growth, increasing in biomass by over 2.5 times that of trees in control plots (Fig. 6). Black oaks and white oaks had similar increases in growth, increasing in biomass by about 2 times that of trees in control plots (Fig. 5 & 7). In black oak control plots, growth rates of black oaks and pitch pines were relatively constant during the last 20 years, but white oaks have shown growth increases since 1988 and are now growing faster than both pitch pines and black oaks (Fig. 8). In white oak control plots, growth rates of black oaks have been stable during the past 20 years, and pitch pines and white oaks have been increasing in growth since 1984 (Fig. 9). Currently, pitch pines are growing the fastest in white oak control plots. In black oak irrigated plots, although all species have increased their growth since 1979, pitch pines and black oaks responded more dramatically to irrigation and have shown the greatest increases in growth during the last 20 years (Fig. 10). In white oak irrigated plots, pitch pines and white oaks showed a greater response to irrigation and have had the greatest increases in biomass during the last 20 years (Fig. 11).

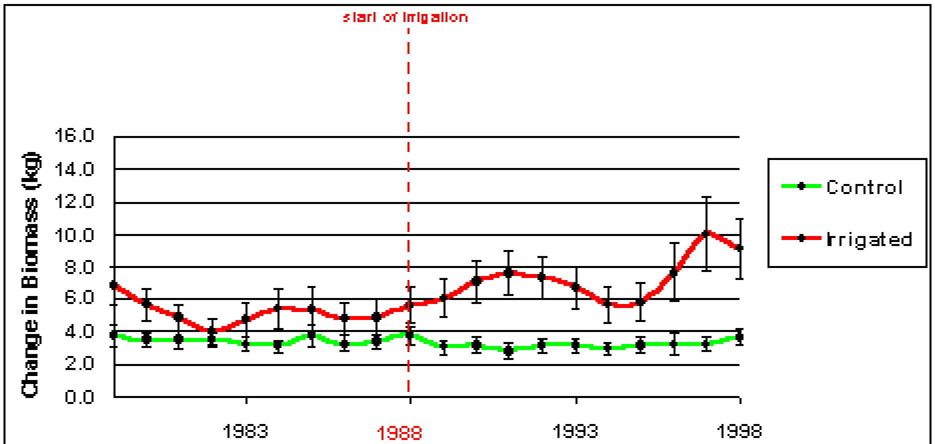

Figure 5. Growth rate of black oaks averaged across plots, 1979-1998.

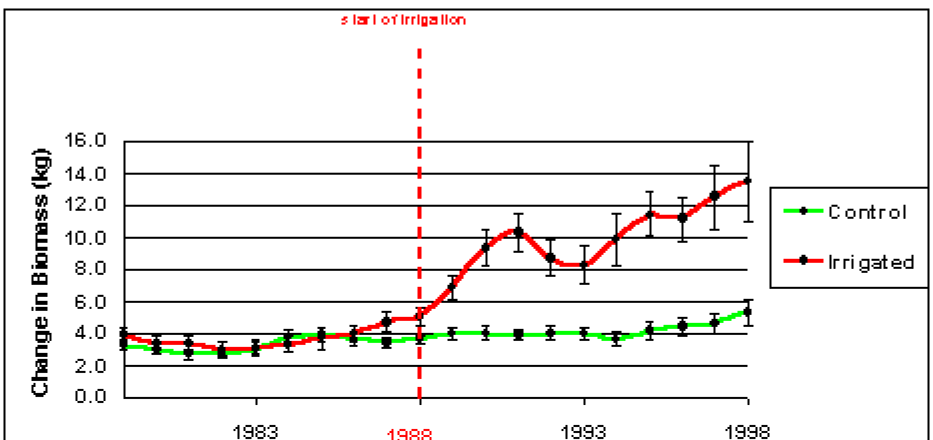

Figure 6. Growth rate of pitch pines averaged across plots, 1979-1998.

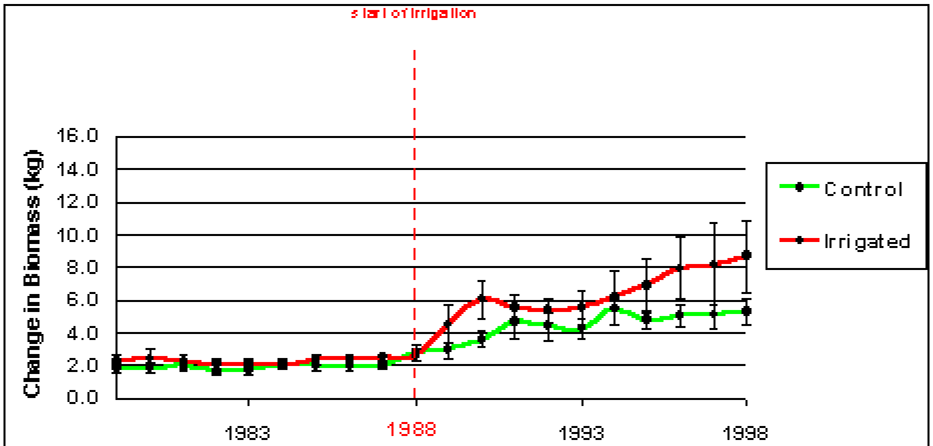

Figure 7. Growth rate of white oaks averaged across plots, 1979-1998.

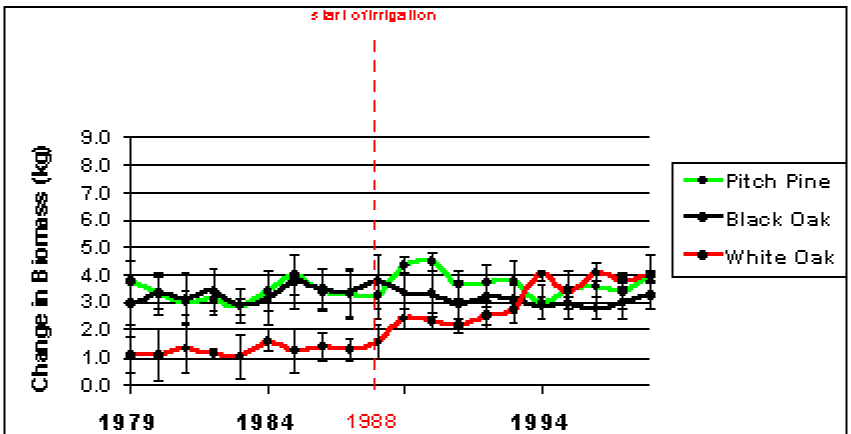

Figure 8. Growth rates of tree species in black oak control plots.

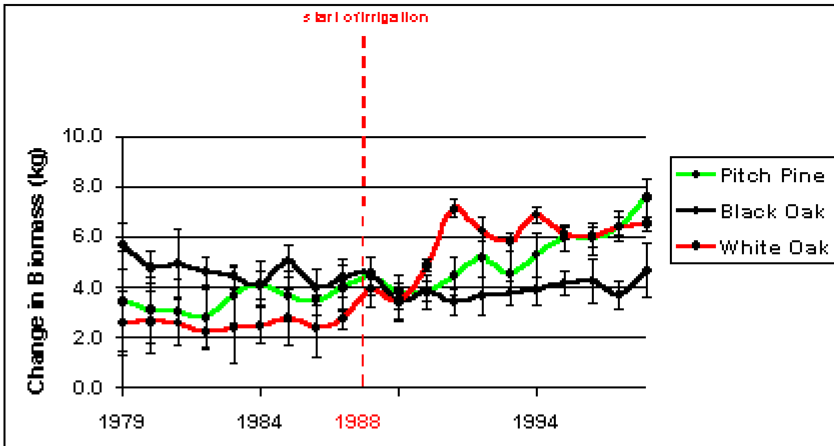

Figure 9. Growth rates of tree species in white oak control plots.

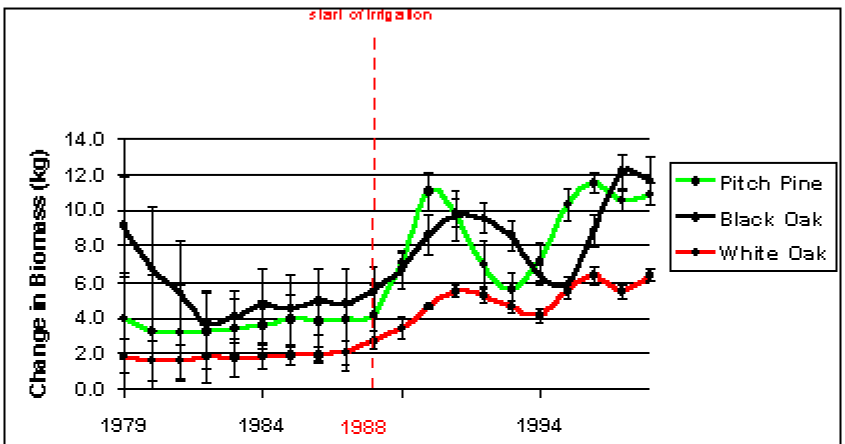

Figure 10. Growth rates of tree species in black oak irrigated plots.

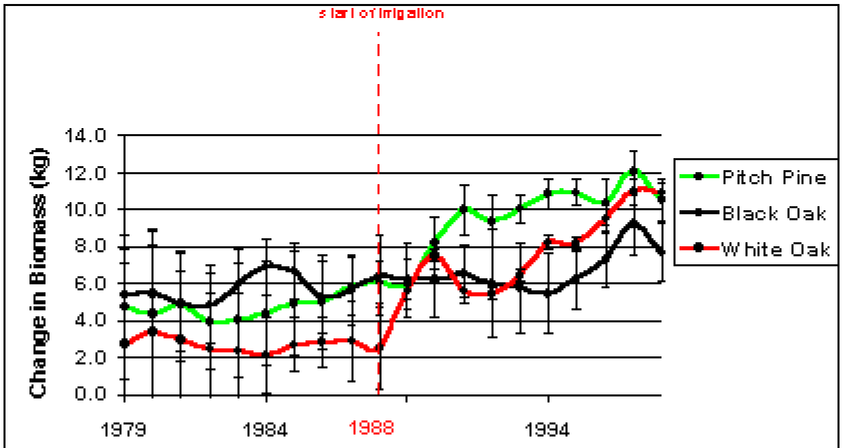

Figure 11. Growth rates of tree species in white oak irrigated plots.

Before irrigation began, all tree species displayed slightly higher growth rates in irrigated plots than control plots with black oaks showing the greatest difference (Fig. 12). After irrigation began, pitch pines showed the largest increase in biomass per tree, followed by black oaks and white oaks respectively (Fig. 13). This trend was also seen in black oak plots (Fig. 14). Although we couldn't compare them to other tree species, pitch pines in pitch pine plots increased in growth by almost 3 times that of trees in control plots (Fig. 15). In white oak plots, growth of pitch pines increased the most with irrigation, followed by white oaks and black oaks respectively (Fig. 16).

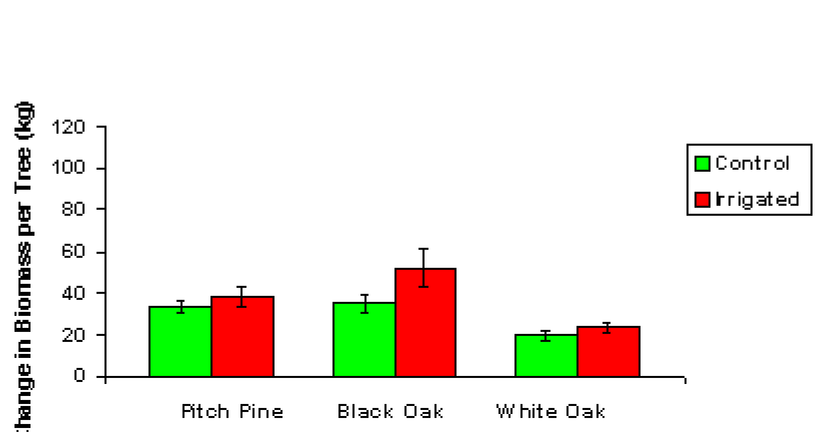

Figure 12. Growth of tree species across treatments 1979-1988.

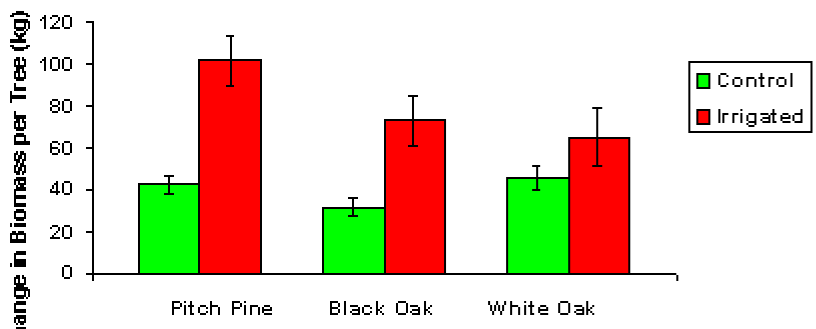

Figure 13. Growth of tree species across treatments 1989-1998.

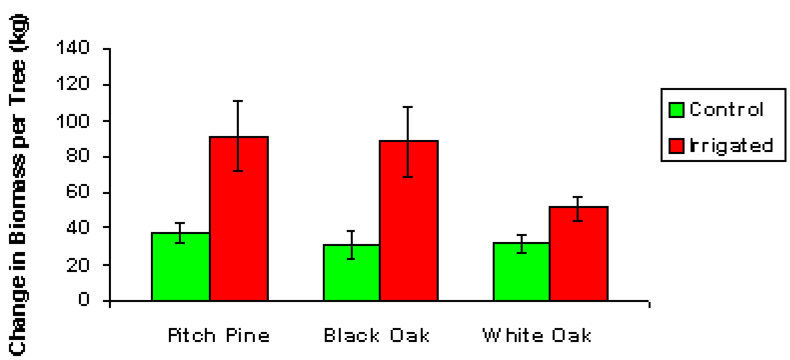

Figure 14. Growth of tree species in black oak plots, 1988-1998.

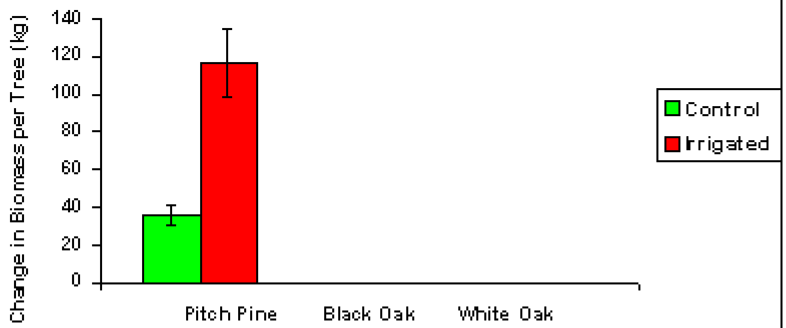

Figure 15. Growth of tree species in pitch pine plots, 1988-1998.

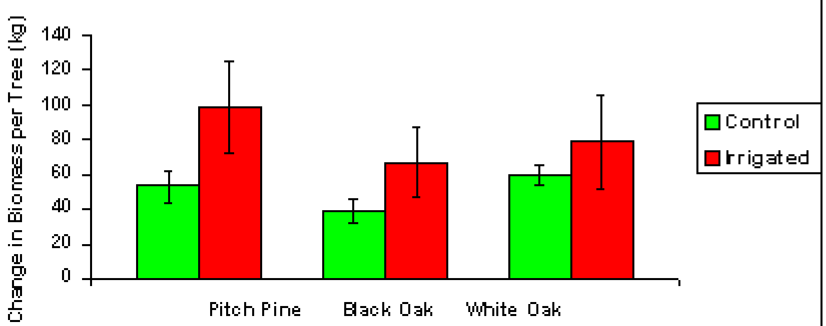

Figure 16. Growth of tree species in white oak plots, 1988-1998.

When comparing the last 10 years of growth to the growth during 1979-1988, pitch pines showed the largest change in percent biomass increase when compared to pitch pines in the control plots (Fig. 17). However, white oaks had the largest percent biomass increase overall, and white oaks even showed large biomass increases in control plots. An ANOVA for this data showed that there was a statistical difference between treatments and species, with P-values of 0.0004 and 0.0001 respectively. The interaction between treatment and species, although not statistically significant, had a P-value of 0.0620. The same trend was also seen in black oak plots and white oak plots (Fig. 18 & 20). In black oak plots, an ANOVA showed that there was a statistical difference between treatments and species with P-values of 0.0011 and 0.0001 respectively. The interaction between treatment and species in black oak plots was not statistically significant but had a P-value of 0.0600. In white oak plots, there was no significant difference between treatments, but a P-value of 0.0120 proved that there was between species. In pitch pine plots, pitch pines increased their biomass by over 300% of that seen during 1979-1988 (Fig. 19). This difference between treatments was also statistically significant, with a P-value of 7.320E-7.

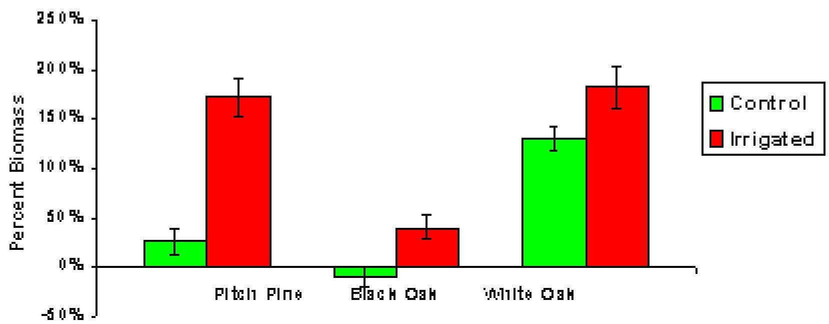

Figure 17. Percent biomass increase of tree species averaged across plots during 1988-1998 vs. 1979-1988.

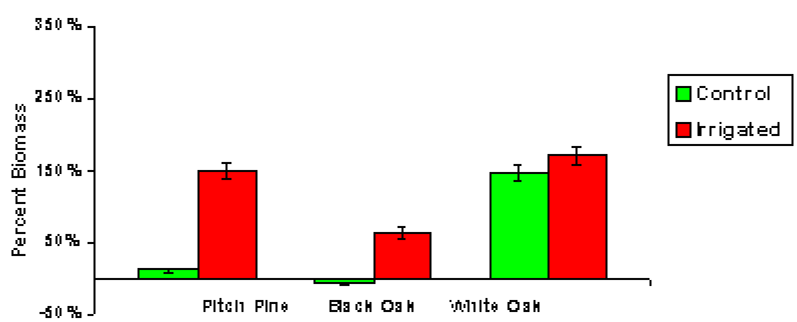

Figure 18. Percent biomass increase of tree species in black oak plots during 1988-1998 vs. 1979-1988.

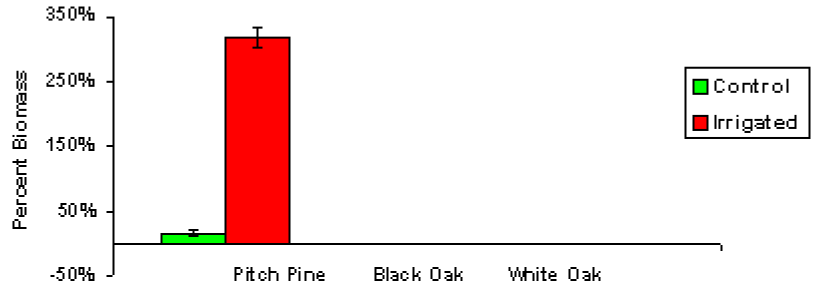

Figure 19. Percent biomass increase of tree species in pitch pine plots during 1988-1998 vs. 1979-1988.

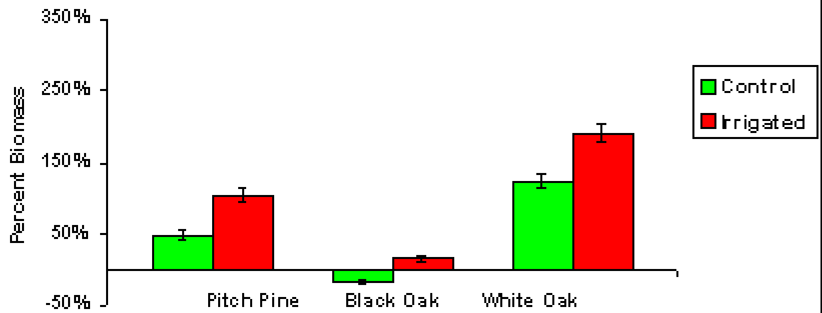

Figure 20. Percent biomass increase of tree species in white oak plots during 1988-1998 vs. 1979-1988.

We discovered that the mean temperature during the growing season since 1979 has remained relatively stable (Fig. 21). Similarly, there have been no dramatic changes in the amount of precipitation received during the growing season in the last 20 years (Fig. 22).

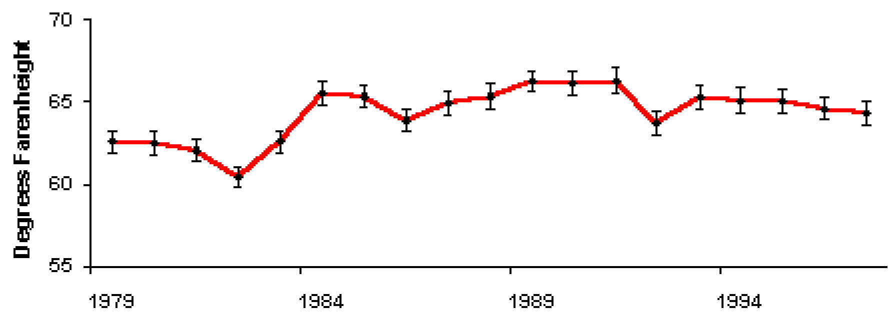

Figure 21. Mean growing season temperature, 1979-1997.

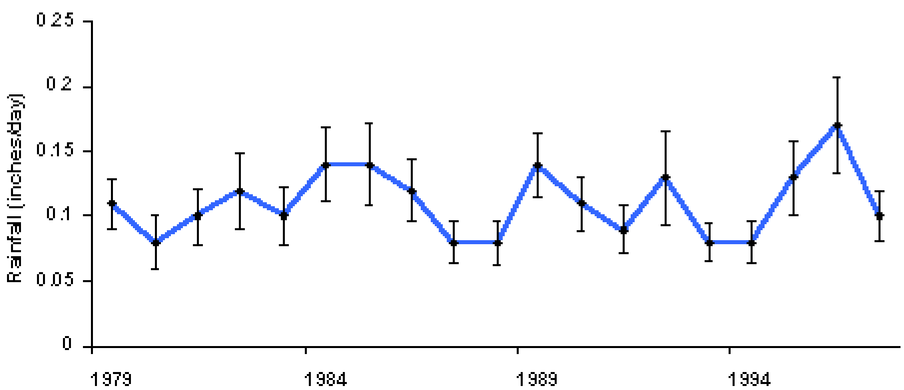

Figure 22. Mean growing season rainfall, 1979-1997.

Discussion

The biomass distribution of tree species seen in both the control and irrigated plots indicates that wastewater irrigation does not dramatically alter the natural species succession of northern hardwood forests (Fig. 3 & 4). However, when comparing the growth responses of each speckles to irrigation, it is evident that wastewater irrigation has a greater impact on pitch pines than either black oaks or white oaks (Fig. 5-7). Pitch pines not only show the largest increases in growth, but also appear to react more quickly to wastewater irrigation (Fig. 10). Despite the rapid increases in growth by pitch pines, this study suggests that wastewater irrigation does not favor subdominant tree species enough to cause a change in species succession. White oaks, being a later successional species on Cape Cod, have a long-term advantage over black oaks and pitch pines (Connor 1994). This can be seen when comparing the growth rates of different tree species in control plots during the last 20 years (Fig. 5-7). White oaks show steady increases in growth beginning around 1988. Increases in Mite oak growth are also apparent in individual black oak plots and white oak plots (Fig. 8 & 9). It is reasonable to assume that conditions in the forest are naturally becoming more favorable for white oak growth. This is supported by the climate data recorded for the last 20 years (Fig. 21 & 22). Since no dramatic changes have occurred in temperature or precipitation, increases in growth of white oaks in control plots is likely a result of forest succession. Although white oaks are not as responsive to wastewater irrigation as pitch pines, they still show respectable increases in biomass during irrigation, and in older stands that are dominated by white oaks, they grow more quickly than any other species (Fig. 11).

In all irrigated plots where white oaks were present, they had the largest percent biomass increase when comparing growth during 1979-1988 to growth during 1988-1998 (Fig. 17-18 & 20). Similarly, large increases were also seen in control plots. This suggests that white oaks are still growing the most rapidly despite the large growth response to irrigation by pitch pines. Because we were only able to analyze growth rates of trees, this study represents only one small aspect of forest succession. Other factors, such as reproductive success, are likely to play a major role in species competition and succession in forest ecosystems.

Conclusion

Our research suggests that, in response to wastewater irrigation, pitch pines show the greatest and most rapid increases in biomass when compared to black oaks and white oaks. It also appears that wastewater irrigation does not alter the species succession of the forest. Consequently, white oaks will still dominate most mature irrigated forests. However, it is difficult to assess the effects that irrigation could have of the rate of forest succession. Faster growth of pitch pines may results in faster succession if these trees die off quickly. On the contrary, increased pitch pine growth may result in healthier trees that could live longer.

Our study indicates that if forests are to be strictly used to remove nitrogen from sewage wastewater, monocultures of pitch pine stands may be the most effective forest composition. Also, if periodical tree harvests are incorporated into forest management, pitch pines would have an even greater advantage over black oaks and white oaks.

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