# NITRATE LEACHING FROM INTENSIVE FOREST MANAGEMENT ON ABANDONED AGRICULTURAL LAND: FIFTH-YEAR RESULTS

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**Abstract—**This report is on the fifth year results of a cooperative research project to examine water quality impacts of maximizing plantation growth on abandoned agricultural land, first reported after two years in the Ninth Southern Silvicultural Research Conference. The study, located on International Paper's Southland Experimental Forest at Bainbridge GA, examines growth of loblolly pine (*Pinus taeda* L.) and sweet gum (*Liquidambar styraciflua* L.) with complete vegetation control, irrigation, fertilization, and pest control as a factorial experiment on an abandoned agricultural field. Groundwater quality was measured in the maximum (all combined) and minimum (only vegetation control), the old field without plantation management, natural forest, and along the shore of Silver Lake. After two years groundwater nitrate concentrations in all the plots in the abandoned field violated drinking water standards (> 10mgN/l) and were significantly higher than the natural forest or lake edge. Soil moisture nitrate was significantly higher in the plots with vegetation control. After five years the number of violations and maximum nitrate concentrations have declined by roughly 50%. Soil moisture nitrate concentrations have declined significantly in the plantation plots in the last three years, at shallow depths. Concentrations at the five foot depth below the minimum treatment plots approached that found in the natural pine < 0.5mg$NO_3$-N /l. Growth rates have been large in all treatments except the sweet gum minimum treatment. Irrigated loblolly plots have accumulated over 250 kgN/ha from the soil pool in the abandoned field. The nitrogen pools within the soil have been sufficient to continue nitrate leaching for five years and supply 200-300 kg N/ha to the control and irrigated (only) pines.

## INTRODUCTION

This paper updates a study first presented in the Ninth Southern Silvicultural Symposium (Williams 1999). The study has been following nitrate leaching on an abandoned peanut (*Arachis hypogaea* L.) field which has been used to grow loblolly pine and sweet gum at accelerated rates. International Paper has installed an experiment to examine highly intensive culture on marginal agricultural land on their Silver Lake experimental area near Bainbridge,GA. In this experiment three replications of four treatments have been applied to sweet gum and loblolly pine. The treatments are: complete competition control, plus irrigation, plus fertigation, plus fertigation and pest control for the maximum treatment. The goal of our section of this project was to evaluate the potential for contamination of groundwater or the adjacent Silver Lake. Groundwater and soil moisture were sampled from five locations in each replication: maximum treatment, minimum treatment, field with no treatment, adjacent natural pine stand, and hardwoods at the edge of Silver Lake. These plots were located as a transect from treated plots downhill to the lake.

Data collected during the first two years of the project confirmed that the direction of subsurface flow was not from the experimental area to the lake. However, the data also clearly showed high concentrations of nitrate nitrogen (NO3-N) beneath the entire old field. Groundwater concentrations peaks were over 27 mg NO3-N/ liter and exceeded EPA drinking water in all points below the field regardless of treatment. All groundwater NO3-N concentrations were significantly (> 10fold) higher than found in the natural forest plots. During the first year the minimum treatment concentration was significantly higher than the old field but this difference disappeared during the second year. Soil moisture NO3-N concentrations were significantly higher in the intensive treatments than in the fallow field and both were also 10 fold higher than the adjacent natural forest.

At that time, the best explanation of the results was tied to decomposition of peanut residues since they had been shown to rapidly release nitrogen (Smith and Sharpley 1990). Also, the higher soil moisture concentrations were thought to be associated with competition control which has been associated with other studies with higher NO3-N concentrations (Likens and others 1969, Munson and others 1993, Neary and others 1986).

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The study has been followed through the fifth growing season. During that period soil moisture and groundwater nitrate has been measured on a quarterly basis. In addition, trees and the forest floor have been measured for biomass and nitrogen uptake. The major questions to be answered have been: 1). Will nitrate leaching continue to be a problem? 2). Does plantation management have a significant impact on nitrogen cycling on the abandoned field?

## METHODS

The study was done at International Paper's Silver Lake Experimental Forest near Bainbridge, GA on a former peanut field near the shore of Silver Lake. Silver Lake is a small stream valley that flooded subsequent to creation of Lake Seminole by a dam on the nearby Flint River. Soils of the site are Lakeland (Typic Quartzipsamments) and Eunola (Aquic Hapludult). In the old field, soils are excessively well drained fine sand to loamy sand.

The plantation management experiment is laid out as three replicates of a randomized block, 2x4 factorial experiment. Factors are species (loblolly and sweet gum) and management intensity (control, irrigation, irrigation + fertilizer, and irrigation + fertilizer + pest control). Since all the blocks had herbaceous competition control and genetically improved seedlings, the controls were still rather intensive cultural treatments.

### Soil Moisture and Groundwater Sampling

Soil moisture and groundwater were examined using multi-level soil moisture and groundwater samplers on three transects, one from each replicate. Each transect consisted of five plots: Minimum treatment(control defined above), Maximum treatment, old field outside of the treatment plots, within a 50 year-old pine stand surrounding the field, and at the edge of the lake. In each replicate, the five plots were aligned perpendicular to the land slope from the field to the lake edge.

In April 1995 a 15 cm diameter hole was augured below the water table and a 5 cm PVC well screen was placed 60 to 120 cm below the water table at each sample location. All plots, except the lake edge, had water tables at approximately 6 meters depth and auger holes were 7 to 7.5 m deep. Horizontal drilling was used to place four (2.5 cm x 10 cm long) tension lysimeters in undisturbed soil approximately 30 cm from the central shaft. Tension lysimeters were connected to sample bottles in a box on the soil surface, and all sample bottles were connected to a central vacuum manifold.

Trees were planted in February 1995 and cultural treatments were begun in April 1995. Sampling of soil moisture and groundwater was begun in May 1995 and samples were collected twice each month until December 1996.

Tension lysimeters were maintained at tensions between 0.5 and 0.7 bar continuously throughout the period. At each sampling, water was poured from the lysimeter sample bottles into 60 ml polyethylene bottles, all 5 cm wells were pumped until clear and a 60 ml sample was collected.

Sampling was discontinued in December 1996 and was resumed in November 1997 and the sampling frequency was reduced. From November 1997 through December 1999 quarterly sampling was done. Groundwater was sampled three times and soil moisture was sampled twice each quarter. At the first visit during the quarter, a groundwater sample would be taken from all the wells. At that time the vacuum pump would be started and 0.5 to 0.7 bar tension would be placed on all of the lysimeters. After each of the next two rains the site would be revisited and samples taken from all wells and lysimeters. During the last visit the pump would be turned off until the first visit in the next quarter.

All samples were placed in coolers and returned to the Baruch Institute Lab in Georgetown SC and nitrate determinations were made within 24 hours. Nitrate analyses were done using cadmium reduction technique on a Technicon autoanalyser (Greenberg and others 1992).

### Biomass and Nitrogen Content Sampling

Trees were planted in rows 3.7 m apart and spaced at 2.4 m within rows and each treatment plot consisted of 12 rows with 18 trees per row. A border 7.3 m wide was established in each plot using the inner 80 trees as a measurement plot. Forty of these were uniformly chosen by skipping every other tree on each row within the measurement plot. Tree growth was measured on three treatments: minimum, irrigated, and maximum, for each replication. For each tree, measurements were basal diameter, diameter at breast height, diameter at base of live crown, height of live crown, and total height. All measures were taken in January of 2000.

Biomass and nutrient accumulation were determined for the maximum and minimum treatments. In addition, the irrigation treatment was also sampled for nutrient content. Twenty trees of each species were sampled to determine biomass-size equations. A fourth replication of the maximum and minimum treatments of both species was designated for destructive sampling. Ten trees of each species from the maximum plot and 10 from the minimum plot were harvested, separated into: stems, dead branches, unfoliated branches, and foliated branches, and were weighed green. Subsamples were dried (60ºC) and weighed to obtain moisture content; subsamples of foliated branches were separated into branches and leaves before drying. Dry weight proportions from subsamples were used to determine dry weight of trees in the following components: stem, dead branches, live unfoliated branches, foliated branches, and leaves. Portions of each subsample were subsequently ground for nutrient analysis.

To assure that all trees measured during the fifth growing season were within the range of trees sampled for biomass, biomass equations were calculated on trees collected after the sixth growing season. Sweet gum trees were collected in September 2000 while loblolly were collected in February of 2001.

Forest floor biomass was estimated on the maximum, irrigated, and minimum plots for each species. In June 2000, all litter (humus layers had not yet formed in any treatment) was removed from 14, 1 m2 areas on a transect extending diagonally across each measurement plot as described above. Plots were stratified into rows (1 m on each side of the tree centers) and inter-rows (greater than 1 m from either row center). Seven areas were collected from each row and inter-row. All litter was carefully scraped from the soil surface and placed into paper bags. Bags were dried (60ºC) and weighed. Subsamples of each bag were ground for nutrient analysis.

All dried subsamples were ground to pass a 1.0mm sieve. The bole samples were chipped prior to grinding in the Wiley mill. Ground materials were Kjeldahl digested (Isaac and Johnson 1976, Labconco 1987, Jones and Case 1990, Jones 1991), diluted with DDW and colorimetrically analyzed for nitrogen and phosphorus with a Technicon AutoAnalyzer II using Industrial Method No. 329-74W/B (Nov. 78 revision) (Technicon Industrial Systems 1978). The nitrogen analysis method uses the sensitive color reaction between NH4+ and alkaline sodium salicylate with a chlorine source (Crooke and Simpson 1971, Technicon Industrial Systems 1978, Nelson and Sommers 1980). Averaged nutrient concentrations were then multiplied by biomass estimates to estimate nutrient quantities.

### Statistical Analysis

Statistical analyses of the groundwater samples were as repeated samples of five treatments and three blocks. On the lake edge no tension lysimeters were installed, since the water table was so close to the surface. Soil moisture samples were analyzed as repeated samples of a factorial with four treatments, four depths, and three blocks. Treatment differences in groundwater within each year were tested by the Tukey multiple range test. Soil moisture concentration comparisons were made between years at a particular depth and across depths within a particular year. These analyses were also tested by Tukey multiple range tests.

Simple linear regressions were calculated for each component and total biomass. Equations were based on the same measures as taken in the growth plots. These regressions were combined with the growth data collected on each treatment to estimate treatment biomass means.

Loblolly equations were:

| | |
|---|---|
| Bole | |
| biomass= 0.00958 D2h + 7.47 | Rsq = .887 |
| Dead Branch= 0.00372 D2h - 3.71 | Rsq = .832 |
| Unfoliated Branches= 0.076 BaBlc -1.82 | Rsq = .624 |
| Foliated Branches=0.0245 BaBlc -1.084 | Rsq = .374 |
| Leaves= 0.00401 BaBlc X Llc + 2.871 | Rsq= .406 |
| | |
| Total Biomass= 0.018 D2H + 14.62 | Rsq = .926 |

Where biomass is in kilograms, D is diameter at breast height in cm, h is total height in m, Bablc is the basal area at the base of the live crown $cm^2$, Llc is length of live crown in m and is total height – height of live crown.

Sweet Gum equations were:

| | |
|---|---|
| Bole= 0.0195 D2h + 1.53 | Rsq = 0.96 |
| Dead Branch= 2.1888 Hlc - 0.1892 | Rsq = 0.86 |
| Unfoliated Branch= 0.677 D - 2.47163 | Rsq = 0.64 |
| Foliated Branch= .00517 (BaBlc x Llc)+ 0.652 | Rsq = 0.65 |
| Leaves= 0.3026 BD - 1.4787 | Rsq = 0.82 |
| | |
| Total Biomass= 0.0305 D2h + 0.9581 | Rsq = 0.96 |

Where units are as defined above and BD is basal diameter in cm and Hlc is height of live crown in m.

Tree part and total biomass were calculated by applying the above equations to each tree measured in the three measurement replication. Average values were then calculated from the aggregated measurements and expressed on a per hectare basis assuming full stocking (1125 t/ha). Nitrogen accumulation was taken by multiplying the appropriate nitrogen content to each tree part and calculation an average tree N content and expressed as per hectare values in the same way.

## RESULTS

Groundwater nitrate nitrogen concentrations are the most important of this study in that NO3-N concentrations above 10 mg/l are above drinking water standards. Concentrations measured above this value represent contamination of the groundwater. Table 1 presents groundwater concentrations for each treatment during the five years on measurement.

**Table 1—Nitrate-nitrogen concentrations in shallow groundwater for each year of measurement. Average concentration during each year followed by the same letter are not significantly different ($\alpha$ = .05). Maximum concentrations in excess of 10 mg NO3-N/l are violations of EPA drinking water standard.**

| Average Concentrations mg NO3-N/l | | | | | |
|---|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 | 1999 |
| Lake Edge | 0.26a | 0.34a | 0.04a | 0.04a | 0.02a |
| Forest | 0.40a | 0.24a | 0.17a | 0.15a | 0.09a |
| Field | 2.46ab | 5.46b | 5.41b | 5.09b | 3.43ab |
| Maximum | 4.82bc | 6.60b | 6.18b | 6.47b | 7.57b |
| Minimum | 6.62c | 8.82b | 6.92b | 7.42b | 8.09b |
| Maximum Concentrations mg NO3-N/l | | | | | |
| Lake Edge | 0.44 | 1.40 | 0.07 | 0.09 | 0.07 |
| Forest | 1.48 | 4.36 | 0.48 | 0.36 | 0.22 |
| Field | 8.49 | 10.67 | 7.75 | 12.48 | 6.86 |
| Maximum | 13.93 | 27.89 | 9.90 | 15.98 | 10.84 |
| Minimum | 19.93 | 17.99 | 9.64 | 17.89 | 13.84 |

The table clearly shows that nitrate nitrogen leaching has continued in the field throughout the five years. There have been violations of the drinking water standard throughout the period also. One must regard the 1997 data with caution since it represents the fall period only during that year and fall samples showed lowest concentrations in all years. With that in mind there has been a decline in the maximum concentrations during the last two years. If this trend is real and continues drinking water violations may cease by year six or seven.

Soil moisture data shows patterns much more clearly than the groundwater data. Since the field was on a Lakeland sand the water table was in excess of six meters below the surface. Impacts of the treatments would most likely first appear at the soil surface and would be expected in the upper soil moisture before the groundwater.

Soil moisture NO3-N concentrations showed considerable variability in both time and space (table 2). Averaged over all depths the forest plot had significantly lower concentrations than the other treatments. There were no significant differences between the other treatments when all depths were considered. In the old field treatment there have been no significant trends in soil moisture NO3-N concentrations. However, there have been significant trends in soil moisture NO3-N concentrations in both the minimum and maximum treatment (table 2). In both treatments there has been a trend toward lower concentrations in the upper soil during the last two years. In 1997 there were fewer data and analyses between depths were not possible. However, at 1.5 meters both the maximum and minimum treatments showed significantly lower concentrations than during the previous years. At this depth the minimum treatment concentrations have remained significantly lower in 1998 and 1999. Also, during 1998 and 1999 the 1.5m depth has also had significantly lower concentrations than deeper depths on the same treatment. During these years the concentration at the 1.5 m depth has been in the same range as the forest treatment. The maximum treatment shows similar trends but the differences were not significant until 1999. Also the reduction in concentration on the maximum treatment appears to extend to the 3 meter depth.

**Table 2—Soil moisture Nitrate – Nitrogen Concentrations (mg NO3-N/l) by depth and year. Within each treatment values followed by the same upper case letter are not significantly different between years within depths. Values with the same lower case letter are not significantly different between depths within years. ( $\alpha$ = .05)**

| Depth (m) | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|
| Forest Treatment* | | | | | |
| 1.5 | 0.82 | 0.30 | 0.08 | 0.25 | 0.02 |
| 3.0 | 0.12 | 0.15 | 0.01 | 0.36 | 1.06 |
| 4.6 | 0.51 | 0.43 | 0.17 | 0.20 | 0.05 |
| Old Field Treatment* | | | | | |
| 1,5 | 3.70 | 8.93 | 2.95 | 6.33 | 2.13 |
| 3.0 | 7.13 | 5.24 | 3.96 | 4.32 | 1.24 |
| 4.6 | 4.56 | 8.67 | 5.84 | 3.70 | 8.74 |
| 6.1 | 4.98 | 5.85 | 7.80 | 4.02 | 6.09 |
| Maximum Treatment | | | | | |
| 1.5 | 11.12 aA | 10.75 aA | 2.808 | 5.46 bA | 0.96 bB |
| 3.0 | 9.50 aA | 6.53 aA | 8.60 A | 2.77 bB | 4.43 abA |
| 4.6 | 11.333 A | 14.43 aA | 6.12 A | 9.63 aA | 9.02 BA |
| 6.1 | 9.488 A | 14.22 aA | 8.07 A | 0.98 aA | 4.01 abA |
| Minimum Treatment | | | | | |
| 1.5 | 9.88 aA | 10.51 aA | 0.798 | 0.23 cB | 0.26 bB |
| 3.0 | 11.54 aA | 10.32 aA | 5.45 A | 6.37 bA | 9.39 aA |
| 4.6 | 12.97 aA | 13.39 aA | 11.01 A | 12.61 aA | 9.42 aA |
| 6.1 | 6.43 aA | 10.57 aA | 6.89 bA | 10.69 aA | |

* No significant differences between depths or years.

## Nitrogen Uptake

During the five years that leaching has been measured the plantations have been growing at very high rates (table 3). Loblolly pine has been much more effective during the first five years in accumulation of both biomass and nitrogen. On the irrigated and minimum treatments these growth rates have been supplied entirely from nitrogen within the old field soil. The loblolly irrigated treatment has been the most effective in accumulating nitrogen form the field soil. The loblolly minimum treatment has accumulated nearly as much. The old field soil contained sufficient nitrogen to sustain rapid growth and accumulation of 173 kgN/ha and continue to show groundwater nitrate-nitrogen concentrations of 8.1 mg NO3-N/l.

The lowered NO3-N concentrations in the upper profile might indicate that uptake is beginning to deplete nitrogen reserves. Data now leaf nitrogen content may also tend to support that view. In table 4 leaf nitrogen contents in the fourth and fifth growing seasons are compared to those measured during the first and second (Samuelson 1998) when soil moisture NO3-N concentrations were uniformly near 10 mg/l. The data in table 4 are has some limitations in that Samuelson (1998) collected leaves in August while the fourth year leaves were collected in May and the fifth in June. McNeil and others (1988) found that loblolly pine

**Table 3— Summary of fifth year growth on measurement plots in maximum growth study. Biomass and nitrogen are expressed assuming 1125 t/ha. Biomass represents only above ground living tree parts but total nitrogen includes nitrogen measured in the forest floor.**

| Treatment | Height | DBH | Total Biomass | Total Nitrogen |
|---|---|---|---|---|
| | m | cm | Mg/ha | kg/ha |
| Loblolly Maximum | 8.63 | 15.6 | 72.7 | 282.8 |
| Loblolly Irrigated | 7.64 | 13.8 | 57.8 | 207.2 |
| Loblolly Minimum | 6.42 | 11.5 | 46.0 | 178.3 |
| Sweet Gum Maximum | 8.18 | 11.1 | 49.9 | 153.2 |
| Sweet Gum Irrigated | 6.16 | 7.6 | 22.5 | 66.9 |
| Sweet Gum Minimum | 4.29 | 4.7 | 10.4 | 43.3 |

needle nutrient content decreases as needles age suggesting that the leaves collected in May and June would be expected to have higher nitrogen content than those collected in August.

Although there was a clear decline in soil moisture NO3-N concentration in the control plots during the third year there were no declines in leaf nitrogen content until the fifth. During the fifth year the nitrogen content of both species in the minimum treatments are considerably lower than during the first four. The decline is larger in the irrigated treatments. This result would be expected since the irrigated treatments are growing considerably faster with the same soil nitrogen pool. The growth and leaf nitrogen data are consistent with the soil moisture NO3-N concentrations.

## SUMMARY

After five years of growth the old field in this study continues to exhibit nitrate leaching. Groundwater NO3-N concentrations are significantly higher in all treatments in the old field than in the adjacent natural pine forest and the hardwoods along the lake edge. Groundwater NO3-N concentrations also continue to have peak values above 10 mg NO3-N/l in all of the old field treatments.

Soil moisture NO3-N concentrations do show significant changes after five years. The surface (1.5m) lysimeters in the minimum treatment shown a significant (both by year at that depth, and by depth within the last three years) declines. Concentrations are below 0.5 mg NO3-N/l and very similar to the surface concentrations found in the natural hardwoods.

Growth rates and nitrogen accumulation have been very rapid during the five years, with accumulations over 200 kgN/ha on sites receiving no fertilization. Leaf nitrogen content declines in the minimum treatment are consistent with depletion of the nitrogen pool within the surface soil. However, the nitrogen pool has been large enough to support accumulation of 173 kgN/ha and produce groundwater NO3-N concentrations that averaged 7.5 mg NO3-N/l for the entire five year period.

**Table 4—Leaf nitrogen content of loblolly needles and sweet gum leaves on experimental plots during the first and second (Samuelson 1998) and fourth and fifth growing seasons. Nitrogen content of leaves (percent)***

| Treatment | 1995 | 1996 | 1998 | 1999 |
|---|---|---|---|---|
| Loblolly Maximum | 1.47 | 1.42 | 1.39 | 1.46 |
| Loblolly Irrigated | 1.22 | 1.28 | 1.20 | 1.03 |
| Loblolly Minimum | 1.10 | 1.28 | 1.31 | 1.09 |
| Sweet Gum Maximum | 2.17 | 2.60 | 3.13 | 2.01 |
| Sweet Gum Irrigated | 2.09 | 2.29 | 2.21 | 1.11 |
| Sweet Gum Minimum | 1.92 | 2.07 | 2.21 | 1.41 |

* First and second year leaves were collected in August, fourth year in late May, and fifth year in June


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