7
Dynamics of Municipal Wastewater Renovation in a Young Conifer-Hardwood Plantation in Michigan

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Since the pioneering work of investigators at The Pennsylvania State University who introduced the "living filter" concept in the 1960s, numerous studies have examined the impact of wastewater irrigation upon forest communities. Some industries had undertaken wastewater recycling measures earlier (Rudolph, 1957; Little et al., 1959), but these met with only modest success, owing, in part, to a limited understanding of the physical and biological capabilities of the sites involved. A wide variety of forest ecosystems have now been treated with wastewater, among these being red pine (Murphy et al., 1973), jack pine (Urie, 1973), aspen (Murphy and Bowier, 1975), oak, birch, and pine (Frost et al., 1973), semiarid chaparral areas (Younger et al., 1973), and a variety of conifer and hardwood species (Sopper and Kardos, 1973).

"Old field" planting sites often present a rigorous set of conditions concerning plantation establishment. A well-developed sod layer usually results in vigorous competition for water and nutrients with the newly planted seedlings. This is particularly true for hardwood seedlings, which are somewhat less adept than conifers in competing with grasses and associated vegetation.

In this study, seven hardwood and three conifer species were planted in an old field and irrigated with municipal wastewater as part of the Michigan State University (MSU) Water Quality Management Area. Major objectives were to (1) monitor water quality changes as percolating effluents interact with the living filter, (2) measure changes in the levels of soil nutrients, and (3) assess the growth response and nutrient status of the tree species employed. Corollary goals included determination of the site's nutrient renovation capacity and detection of possible nutrient toxicity symptoms.

Materials and Methods

The study site is a 2.1-ha old field area located 5 km south of the main campus of MSU in East Lansing. Gently rolling glacial till, 20 m in depth, overlay a bedrock of Saginaw sandstone (Martin, 1936) and supported native vegetation dominated by a beech-maple forest prior to cultivation.

A well-developed sod layer and vigorous herbaceous growth, including *Solidago, Digitaria, Agropyron,* and *Andropogon,* existed at reforestation time. The Miami-Conover-Brookston alfisol soil catena comprises most of this area along with a minor component of the Spinks series (Figure 7-1). Annual precipitation averages 765 mm (30 in.). Sewage effluent obtained from the East Lansing Municipal Waste Treatment Facility is cycled through a system of four lakes ranging in size from 3 to 5 ha, with each successive lake representing a higher stage of quality. Water from the first lake, highest in nutrient

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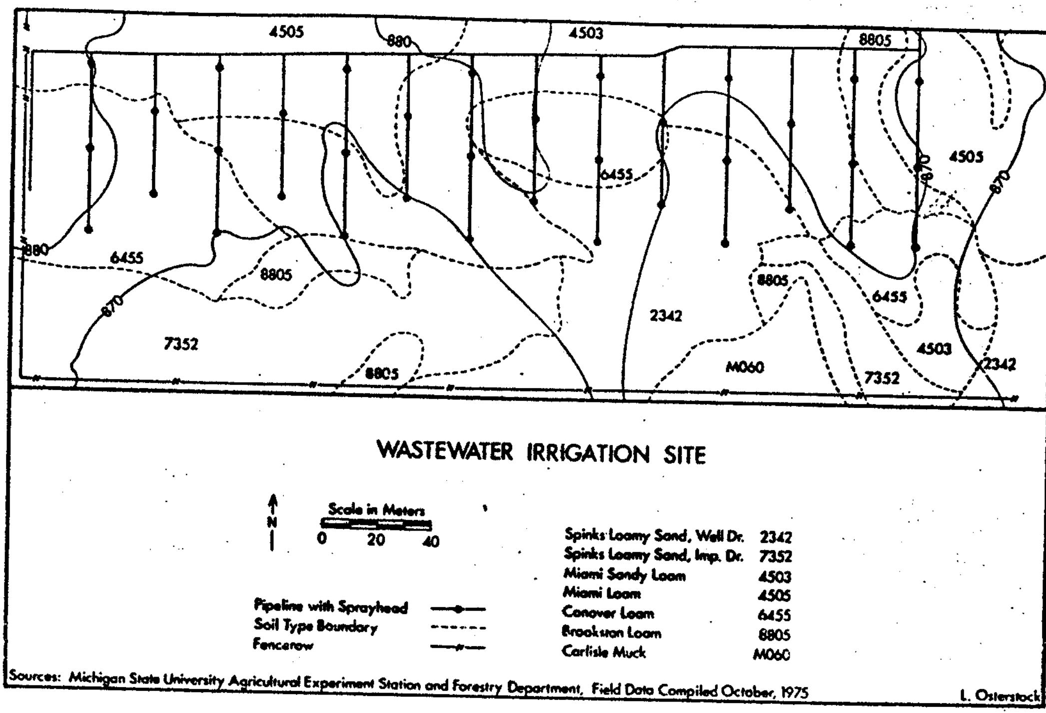

Figure 7-1. Wastewater plantation site: soils, topography, and irrigation lines

content, was delivered to the study site by means of an overhead spray irrigation system consisting of 39 Buchner No. 8600 sprayheads spaced 25 × 30 m.

The plantation was established in April 1974 following weed control treatment with a herbicide mix of paraquat-CL 1.1 kg/ha (1 lb/acre) and simazine 2.2 kg/ha (2 lb/acre). The 10 tree species planted were American sycamore (*Platanus occidentalis*), black cherry (*Prunus serotina*), black walnut (*Juglans nigra*), eastern cottonwood (*Populus deltoides*), northern red oak (*Quercus rubra*), white ash (*Fraxinus americana*), tulip poplar (*Liriodendron tulipifera*), Scotch pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and white spruce (*Picea glauca*). The experimental design consists of 14 replications in a randomized complete block. Each replication contains 10 rows, each 62.8 m (200 ft) long and containing 40 individual trees of a single species, totaling 5600 seedlings for the entire plantation. Spacing is 1.5 × 2.1 m (5 × 7 ft), with each replication delineated by the intervening irrigation lines. Replication 1 was the control plot, receiving no irrigation, while replications 2 through 14 were treated with 51 mm of effluent per week, for 15 weeks each season.

Weekly samples of irrigation water were taken from sprayheads while groundwater samples were obtained with 15 suction lysimeters, stratified by soil type, topography, and treatment and placed 61 cm into the soil. Each lysimeter was evacuated to 33 cm of mercury, and sampled weekly from July 1975 through September 1976. Water-sample pH was recorded using a Cole-Parmer Digi Sense pH meter and the sample preserved using concentrated sulfuric acid (1 ml/600 ml) or concentrated nitric acid (1 ml/300 ml), depending upon the ionic species for which analysis was desired. All water samples were placed in cold storage until analysis could be conducted by the MSU Institute of Water Quality or the WARF Institute of Madison, Wisconsin.

Soil samples were collected in May and September 1975 and in September 1976 at depths of 0 to 15, 15 to 30, 45 to 60, and 105 to 120 cm. Sampling was conducted in systematic fashion so as to obtain four samples from each of 36 loci at evenly spaced intervals across the plantation. Soil samples were air-dried, composited by horizon and soil type, pulverized, and passed through a 2-mm screen. Soil nutrient analyses were performed by the MSU Soil Chemistry Laboratory and A & L Agricultural Laboratories of Fort Wayne, Indiana.

Assessment of seedling growth and nutrient status was made in September 1975 and 1976 following each irrigation season. Foliage samples were taken from all seedlings in replications 1 through 10 and composited by row. One tree was selected from each previously sampled row and clipped at groundline. Total height and basal stem diameter were recorded in the field.

Oven-dry weights (75°C) of the total tree, foliage, branch, and stem components were determined. The oven-dry foliar sample from each row was ground in a Wiley mill and passed through a 30-mesh screen (Van Den Dreissche, 1974). Total nitrogen (TN) was determined by the macro-Kjeldahl method. Potassium (K) determinations were accomplished by water extraction and the leachate analyzed by flame spectrophotometry. A mass spectrograph was used to determine foliar contents of boron (B), calcium (Ca), phosphorus (P), sodium (Na), magnesium (Mg), manganese (Mn), and zinc (Zn) (Issac and Kerber, 1971).

Results and Discussion

Water Quality

Irrigation Volume. Wastewater volumes delivered during the growing season to the plantation site consisted of precipitation equivalents of 261 mm (10.3 in.) in 1974, 718 mm (28.3 in.) in 1975, and 815 mm (32.1 in.) in 1976.

A systematic irrigation schedule was not fully operative until August 1974, resulting in the low level of water applied during the first year. The weekly irrigation level averaged 50.8 mm, applied in at least two treatment periods, approximately 25.4 mm each (Figure 7-2). The application rate was approximately 4.2 mm/hr.

Groundwater Recharge. Groundwater recharge was computed using the method of Thornthwaite and Mather (1957) and utilizing weather station data obtained 2 km from the site. In June 1975, there was no net groundwater recharge as potential evapotranspiration (PE) exceeded the total monthly precipitation (Table 7-1). This is normal for the study locale. However, with increased irrigation volumes, a net groundwater recharge occurred for the balance of the season. The 1975 season was an abnormally wet year, a fact that greatly affected soil nutrients and seedling growth during 1975 and 1976. August was an unseasonably wet month (180.2 mm) and, along with normal irrigation levels, produced massive hydrologic site loading, which probably accounts for high tree mortality in the low swale areas, presumably from root oxygen stress.

The 1976 growing season was a drier period than the previous year (Table 7-1). Although monthly PE exceeded monthly rainfall, it was, in turn, exceeded by monthly irrigation. Hence a consistent groundwater recharge occurred during each month of the 1976 growing season.

Of the eight months examined, over a 2-year period, only during August 1975 did rainfall exceed PE. Groundwater recharge due to irrigation occurred in all months except June 1975, when combined rainfall and irrigation were not substantial enough to exceed PE.

Nutrient Loading. Nitrate (NO_3) levels were lower in 1975 effluent, resulting in light loading, whereas the 1976 NO_3 load was seen to increase (Table 7-2). During 1975, effluent NO_3 levels were well within the safe limit of 10 parts per million (ppm), while

Figure 7-2. Wastewater irrigation in progress, summer 1975

1976 effluent exceeded that limit in June with 15.6 ppm and September with 12.4 ppm. Nitrate losses to groundwater, however, were small. Ammonium (NH_4) values, which were higher in 1975, decreased in 1976. Loading of TN was moderate, at 91.7 kg/ha for 1975 and 116.7 kg/ha for 1976. Total N losses to groundwater were low, unlike those of NH_4 in 1975.

Phosphorus loading values of 9.1 and 30.0 kg/ha, although increasing from 1975 to

Table 7-1. Thornthwaite water-budget calculations for wastewater renovation of Michigan study site, 1975 and 1976

	1975				1976			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Mean monthly temp., 1940 to 1969 (°C)	19.3	21.3	20.5	16.4	19.3	21.3	20.5	16.4
Mean monthly temp., 1975 to 1976 (°C)	19.3	20.2	20.1	13.4	20.0	20.8	18.3	14.4
Heat index	7.73	8.28	8.22	4.45	8.16	8.66	7.13	4.96
Unadj. daily PE (mm)	3.1	3.3	3.2	2.1	3.2	3.4	2.9	2.3
12-hr sunlight units	1.27	1.25	1.15	1.04	1.27	1.25	1.15	1.04
Lat. corr. factor	48.4	48.4	41.1	32.4	48.4	48.4	41.1	32.4
Adj. monthly PE (mm)	150.0	159.7	131.5	68.0	154.9	164.6	119.2	74.5
Monthly rainfall (mm)	20.6	68.3	180.2	62.6	96.1	126.9	11.4	44.1
Monthly irrigation (mm)	115.8	253.0	264.2	81.3	111.7	276.8	251.5	175.3
Monthly precipitation (mm)	136.4	321.3	444.4	143.9	207.8	403.7	262.9	219.4
Net precipitation (mm)	−13.6	161.6	312.9	75.9	52.9	239.1	143.7	144.9
Accum. water loss (mm)	−13.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soil water storage (%)	86.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Soil water storage change (mm)	−13.6	+13.6	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater recharge (mm)	0.0	148.0	312.9	75.9	52.9	239.1	143.7	144.9

Table 7-2. Michigan study site nutrient balance sheet (kg/ha) for the 1975 and 1976 growing seasons

Nutrients	1975 Nutrient Load with Irrigation	1975 Nutrient Escape to Groundwater	1976 Nutrient Load with Irrigation	1976 Nutrient Escape to Groundwater
NO_3	62.9	[a]	80.5	19.1
NH_4	28.7	30.6[b]	19.8	4.8
Total N	91.7	32.9	116.7	30.4
P	9.1	0.5	30.0	0.56
K	174.9	55.8	78.7	[c]
Na	1705.9	487.4	709.0	244.8
Ca	1409.3	761.3	615.4	290.1
Mg	624.7	286.0	210.3	107.9
B	5.5	1.6	0.52	1.24[b]
Mn	2.1	35.5[b]	0.82	4.82[b]
Zn	0.9	8.0[b]	0.39	3.97[b]

[a]Groundwater concentrations of NO_3 unobtainable.
[b]Net loss from the site.
[c]Groundwater concentrations of K below detectable limits.

1976, showed excellent on-site retention. Under adverse environmental conditions the initial loading rate of Na, 1705.9 kg/ha, could be expected to lead to soil salinity problems. However, as a result of abundant irrigation water volumes and normal PE levels, Na is not expected to become the major problem it is on other sites. Loading and loss rates of other macronutrients were moderate in both years.

In 1975, B effluent levels were moderately low. Boron loading exceeded loss to groundwater, with a net site gain. In 1976, however, B effluent levels declined. This resulted in little B loading, an increased loss to groundwater, and a net site loss. Soil B levels were probably brought into equilibrium with irrigation effluent levels by leaching of the H_3BO_3 form. Both Mn and Zn showed low loading rates and substantial losses to groundwater during both seasons. This is attributed to flushing by irrigation water low in these two nutrients.

Nutrient Renovation. The most striking feature of June 1975 is that all nutrients show 100% renovation (Table 7-3). Because of the lack of groundwater recharge during June, site capture of all applied nutrients occurred. As the season progressed, however, micronutrient renovation became nil. Note similar results for NH_4-nitrogen. This is ostensibly due to the flushing action of both high rainfall and irrigation water that is low in these

Table 7-3. Percent nutrient renovation of the Michigan study site for the 1975 and 1976 growing seasons

Nutrient	June	July	Aug.	Sept.	Mean	June	July	Aug.	Sept.	Mean
NO_3	100.0	[a]	[a]	[a]	[a]	97.2	60.8	72.8	77.9	76.3
NH_4	100.0	0.0	0.0	39.0	0.0	0.0	74.2	84.6	73.1	75.8
Total N	100.0	52.2	40.0	77.5	64.1	85.4	63.8	75.8	75.9	74.0
P	100.0	97.7	62.2	95.8	94.5	99.4	98.9	99.7	94.7	98.1
K	100.0	75.2	50.2	57.6	68.1	[b]	[b]	[b]	[b]	[b]
Na	100.0	90.7	21.8	40.9	71.4	90.6	69.1	69.9	37.9	65.5
Ca	100.0	73.5	0.0	38.8	45.9	78.6	51.1	61.9	25.1	52.9
Mg	100.0	79.9	12.8	31.1	54.2	75.1	46.1	55.3	23.1	48.7
B	100.0	86.4	54.8	11.4	70.9	33.3	0.0	0.0	0.0	0.0
Mn	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[a]Groundwater NO_3 levels unobtainable.
[b]Groundwater K levels below detectable limit.

nutrients. Excessive leaching carried these nutrients through the soil at rates too rapid to allow for optimal soil adsorption. In spite of these hydrologic complications, however, 1975 renovation of P, K, and B exceeded 94, 68, and 70%, respectively.

Nutrient renovation of 1976 wastewater is a reflection of the more normal weather pattern. Excessive rainfall was not a confounding factor, so nutrient renovation primarily became a function of effluent nutrient concentrations and soil adsorption. Total nitrogen renovation was 74% in 1976, a notable improvement over 64% obtained in 1975. Phosphorus renovation exceeded 98%. Groundwater concentrations of K were below detectable limits. Sodium, Ca, and Mg were moderately renovated. Boron showed little renovation in 1976, owing to a low effluent concentration—0.025 ppm—which resulted in nutrient flushing. Manganese and Zn renovation was zero as a result of the season-long flushing of the native soil reserves of these elements.

The soils on this site appear to function as a single renovation unit. No significant renovation differences could be discerned between ridges and swales (*t*-test) or among soil types (*F*-test) at the 0.05 confidence level.

Soil Chemistry

Fluctuation in soil nutrient levels was observed in 1975 and 1976. However, owing to the highly variable nature of the soils and topography of the site, a detailed budget of nutrient gains and losses was unobtainable. The following discussion, therefore, deals primarily with preliminary trends of soil nutrient fluctuation.

Soil pH. Soil pH during 1975 increased in the upper soil horizons and decreased at greater depths (Figure 7-3). Cation bases, Ca, Mg, K, and Na, loaded in low-to-moderate amounts, may have been adsorbed onto soil colloids, with resulting exchanges for aluminum and hydrogen ions. This cation exchange, with subsequent formation of the hydrated hydroxyaluminum ion, is believed responsible for pH increases in the surface horizon (Tisdale and Nelson, 1967).

The pH decrease shown in the lower horizons is probably a sampling artifact encountered with these highly variable soils. In 1976, pH increases occurred in all horizons, an anticipated event considering the basic reaction of the irrigation effluent (pH 7.7).

Macronutrients. Soil nutrient profiles over the 2-year irrigation period are shown in Figures 7-3 to 7-9. Total nitrogen is accumulating within the soil profile. However, while NO_3 is accumulating in the profile, NH_4^+ shows an overall decline (Figure 7-4). This

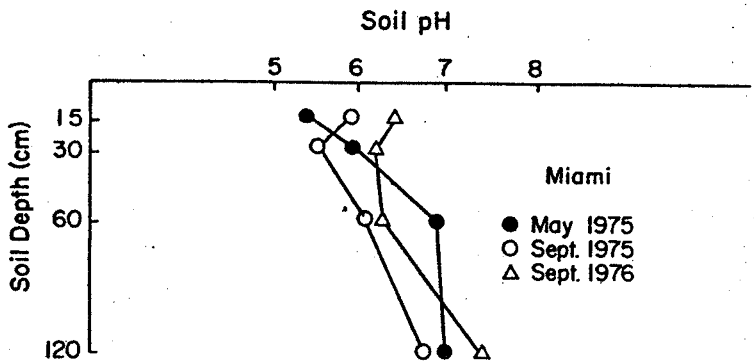

Figure 7-3. The pH profile in the Miami soil following wastewater irrigation for the 1975 and 1976 growing seasons

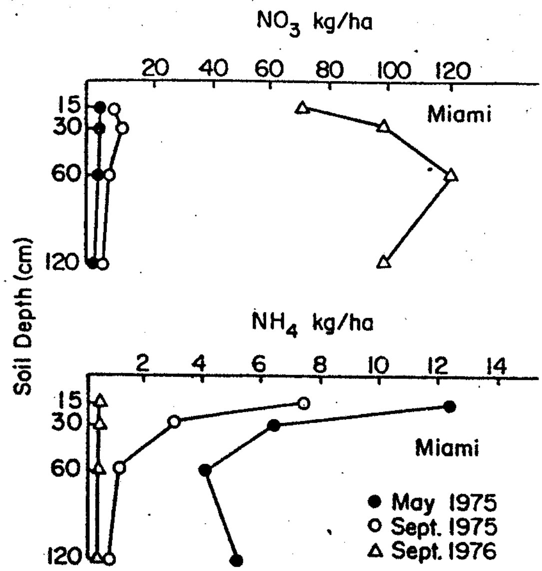

Figure 7-4. Nitrate and NH_4 profiles in the Miami soil following wastewater irrigation for the 1975 and 1976 growing seasons

decrease in NH_4 level may be due to (1) replacement of NH_4 in the cation-exchange complex by other cations, making it more susceptible to leaching loss; or (2) nitrification of NH_4 to NO_3, which could, in part, account for the soil NO_3 increases observed (Harmsen and Kolenbrander, 1965). Increases in soil NO_3 levels may also be due to high NO_3 concentrations in the effluent.

Soil P-level fluctuations, although somewhat complex, exhibit a progressive increase in the surface horizons (Figure 7-5). Ellis (1973) reports P capacities ranging from 69 kg/ha for dune sand to 810 kg/ha for Warsaw loam. The study site was probably initially

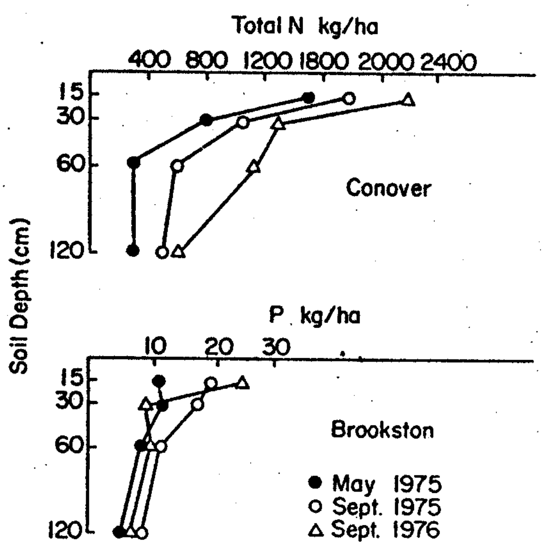

Figure 7-5. Total N profile in the Conover soil and the P profile in the Brookston soil following wastewater irrigation for the 1975 and 1976 growing seasons

low in P, 10 kg/ha, accounting for the accumulation observed. The P adsorption capacity may be quite high and could lead to excellent long-term renovation.

The profile of soil K undoubtedly reflected the high 1975 rainfall, which resulted in initial decreases of this mobile nutrient in all but the uppermost horizon (Figure 7-6). Although the K equilibrium was stressed by early leaching, accumulations of soil K have been more than restored to original levels by 1976. Total carbon (C) levels in the soil follow a pattern similar to that of K. Accumulations of C in 1976 are though to be due to organic matter loaded in the effluent and accelerated decomposition of surface litter (Neary, 1974).

Sodium is slowly increasing in all horizons as irrigation progresses. Excessive Na loading (Figure 7-7) has been shown to be responsible for degradation of soil structure, particularly in soils of finer texture (Ellis, 1973). Sodium is not expected to become a detrimental factor on this study site, as both initial soil levels and current loading rates are low. The irrigation water quality was found to be satisfactory with a sodium adsorption ratio (SAR) calculated to be 2.27, well within the low-risk area of Na increases.

$$SAR = \frac{\text{me Na}^{+}}{\sqrt{(\text{me Mg}^{2+} + \text{me Ca}^{2-})/2}}$$

High-Na-risk areas would have a SAR exceeding 12.0 at the observed electrical conductivity of 900 μmhos/cm.

Both Ca and Mg showed an initial decrease in 1975, presumably because of heavy rainfall, followed by a substantial accumulation by the end of the subsequent season (Figure 7-8). Loading rates of these elements are low in comparison with the magnitudes employed by modern agricultural liming practice. On-site retention is satisfactory as indicated by levels present in the groundwater.

Micronutrients. Micronutrients are reported to be sensitive to soil moisture conditions. High levels of soil moisture increase the mobility of Mn and Zn (Figure 7-9), making them more subject to loss by leaching (Lucas and Knezek, 1973). High rainfall provided a massive groundwater recharge in 1975, while micronutrient concentrations were low

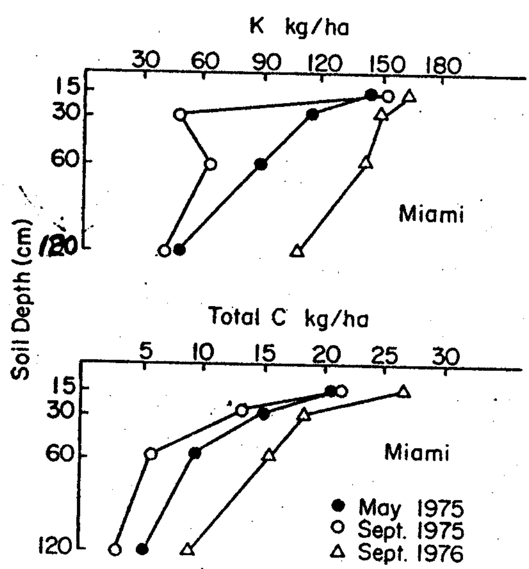

Figure 7-6. Potassium and total C profiles in the Miami soil following wastewater irrigation for the 1975 and 1976 growing seasons

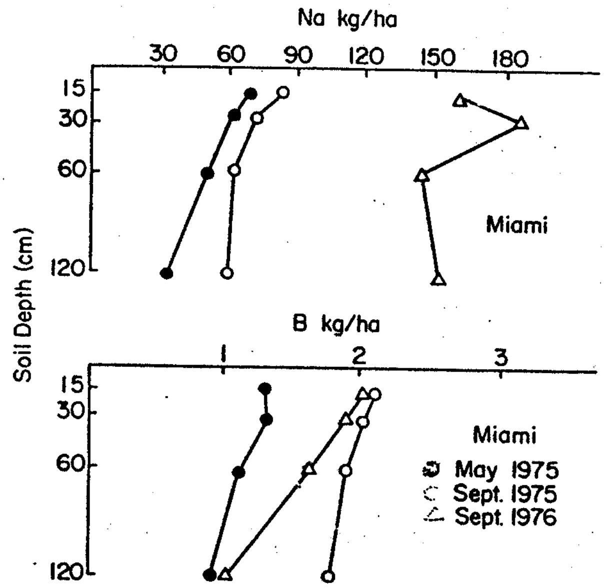

Figure 7-7. Sodium and B profiles in the Miami soil following wastewater irrigation for the 1975 and 1976 growing seasons

in irrigation effluent in 1975 and 1976. Boron concentrations were much less in 1976 effluent than in 1975.

During the 1975 season, B accumulated in all soil horizons. Possible mechanisms include (1) B adsorption upon the aluminum and hydroxy compounds associated with clay particles, and (2) formation of the borate-diol complex with soil organic matter. In 1976, however, effluent B experienced a sharp decrease, which resulted in a slight leach-

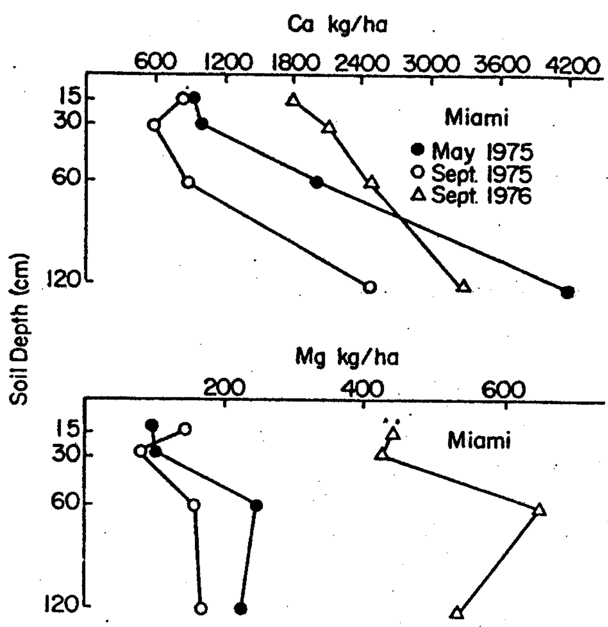

Figure 7-8. Calcium and Mg profiles in the Miami soil following wastewater irrigation for the 1975 and 1976 growing seasons

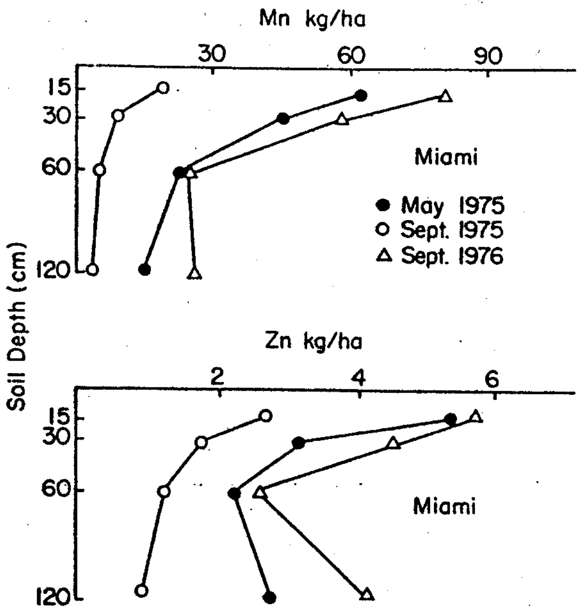

Figure 7-9. Manganese and Zn profiles in the Miami soil following wastewater irrigation for the 1975 and 1976 growing seasons

ing of B from the soil in the H_3BO_3 form. Soil B levels are known to be variable (7 to 80 ppm) and are here present in low levels, less than 2 kg/ha.

Soil Mn data suggest a notable decrease. The 1975 loading rate of 2.1 kg/ha was far less than the estimated loss to groundwater of 35.5 kg/ha, indicating a large site loss, most probably due to leaching of the Mn^{2+} form. The apparent 1976 increase in Mn seen in the soil profile is most likely due to the high site variability discussed earlier and is uncorroborated by site losses reported in Table 7-2. The pattern of soil Zn fluctuation at this time does not exhibit a definitive trend. The rise and fall of Zn levels are most probably a product of natural soil variability.

Seedling Growth

A nearly universal effect of nutrient-rich wastewater irrigation is to increase the rates of vegetative growth. In woody plants, water increments primarily stimulate height growth, while nutrients are primarily responsible for diameter increases (Einspahr et al., 1972).

Wastewater irrigation of young trees planted in this experiment has thus far shown little significant increase in growth over unirrigated controls (Table 7-4). Significant differences for some growth parameters occurred in some species, but no general trend is apparent. The initial responses of white spruce and black walnut were significant with regard to height and diameter, respectively; however, currently only tulip poplar and white ash show significant variation in these categories. Tulip poplar is the only species to thus far show significantly greater biomass accumulation over its controls.

The heavy 1975 rainfall may have contributed to the growth of control trees as much as it may have inhibited metabolic processes of certain treated trees. This probably masked the expected growth differential between treated and control seedlings, since the growth of many woody species in any single year is dependent upon the water supply during the previous as well as present year (Clements, 1970, 1971; Garret and Zahner, 1973).

A comparison among the various species in this plantation shows cottonwood to be the single species best suited to wastewater irrigation. Its response in biomass accumula-

Table 7-4. Species growth response to wastewater irrigation over three growing seasons[a]

Species	Height (cm)		Basal Stem Diameter (cm)		Shoot Dry Wt (g)		Leaf Wt/ Dry Wt (%)		Twig Wt/ Dry Wt (%)		Stem Wt/ Dry Wt (%)	
	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976
Scotch pine	62.6	78.6	1.82	2.86	113	429	47	41	23	21	30	38
Norway spruce	60.1	69.1	1.54	1.92	76	186	39[b]	39	17	14	44	47
White spruce	37.3[b]	49.6	1.09	1.38	32	69	36	42	16	17	48[b]	41
Black walnut	68.2	109.1	1.65[b]	1.81	94	248	40	33	30[b]	15	30	52
Black cherry	—	120.4	—	2.04	—	151	—	25	—	31	—	44
Tulip poplar	—	123.0[b]	—	2.54[b]	—	189[b]	—	32	—	14	—	54
White ash	63.2	124.7[b]	1.28	2.13[b]	38	151	36	28	14	20	50[b]	52
Red oak	70.1	99.9	1.22	1.63	55	141	46	42	15[b]	11	39	47
Cottonwood	165.0	211.2	2.45	3.96	336	966	37	35	25	23[b]	38	42
Sycamore	—	131.0	—	2.32	—	548	—	40	—	29	—	31

[a] $N = 9$.
[b] Significantly greater than control (0.05 level).

tion and especially height attainment surpasses all other species. This response was expected, considering the rapid growth rate and hydrophilic nature of the species. Sycamore is rated as second best in response and Scotch pine as third best. Although Scotch pine has not shown the height response of the hardwoods, its biomass and diameter growth is superior to all but cottonwood and sycamore. Black walnut was also a species with a significant response. In spite of its well-known determinate growth pattern, it underwent a growth flush of longer duration in early season and retained its leaves for a longer period in the late summer. This produced seedlings of notable size and weight.

Irrigation extends the season during which growth may occur. Howe (1968) reported an extended growing season in Idaho for irrigated ponderosa pine, while Kaufman (1968) found a similar result for white and loblolly pines. When exposed to water stress, these pine seedlings underwent root suberization, which precipitated the onset of dormancy. If water stress is severe, the intercalary regions along each shoot may go dormant as well. Flushes of growth observed in this plantation extended much later into the summer season for treated seedlings than for controls. Numerous late summer growth flushes were observed, presumably resulting from continuous favorable soil moisture conditions.

In examining the component biomass distribution of each species with time, the percentage of biomass comprising the leaves and twigs is decreasing, while that of the stem wood is increasing. Only white spruce appears to contradict this trend.

Foliar Nutrients

The foliar nutrient concentrations of treated seedlings following irrigation over three growing seasons are summarized in Table 7-5. Significant variation existed between treated and control groups. For all species combined, the average foliar nutrient increases were: Na, 365.2%; K, 47.5%; B, 41.5%; Ca, 33.2%; N, 21.7%; P, 19.0%; and Mg, 17.4%. Manganese and Zn showed decreases of 13.2 and 13.0%, respectively, when compared with controls.

In general, the foliar nutrient levels are in the low-to-intermediate range of tolerable nutrient limits that have been reported for these species. No exceptional foliar nutrient increases have resulted thus far from irrigation treatment. This is to be expected, as the seedlings are still quite small and have not had the opportunity to fully occupy the site with an extensive root system. With stand maturity, larger amounts of nutrients will be assimilated by a better-developed root network. Presently, nutrient renovation appears to be primarily accomplished by the soil matrix.

Table 7-5. Foliar nutrient concentrations by species following wastewater irrigation over three growing seasons[a]

Species	N (%)		P (%)		K (%)		Na (%)		Ca (%)		Mg (%)		B (ppm)		Mn (ppm)		Zn (ppm)	
	'75	'76	'75	'76	'75	'76	'75	'76	'75	'76	'75	'76	'75	'76	'75	'76	'75	'76
Scotch pine	1.8	2.4[b]	0.16	0.22[b]	0.37	0.75	0.14[b]	0.10[b]	0.35	0.54[b]	0.10	0.13[b]	30.4	40.0	300.4	289.8[b]	33.7	50.0
Norway spruce	2.3	2.4[b]	0.24	0.27[b]	0.40	0.76	0.13	0.16[b]	0.87	1.26[b]	0.17	0.19[b]	26.8	42.6[b]	564.1	397.7	40.6[b]	42.2
White spruce	2.2	2.1[b]	0.22	0.21[b]	0.30	0.56	0.11[b]	0.09[b]	1.17[b]	1.10[b]	0.30[b]	0.16[b]	22.4	35.8[b]	487.7[b]	346.2	32.5	38.4
Black walnut	2.4	2.5	0.19	0.22	0.75	1.67[b]	0.21[b]	0.10	1.48	1.69[b]	0.50[b]	0.37[b]	36.3	64.0[b]	193.9	169.3	40.2	28.5
Black cherry	—	3.3[b]	—	0.27	—	1.03	—	0.01	—	1.51[b]	—	0.27	—	24.1[b]	—	273.8	—	25.3
Tulip poplar	—	2.6	—	0.25[b]	—	1.23[b]	—	0.06	—	1.16	—	0.35	—	36.0[b]	—	155.9[b]	—	15.8
White ash	2.3[b]	2.2	0.21	0.25	0.61[b]	1.12	0.09[b]	0.16[b]	1.17	1.17[b]	0.30	0.34[b]	29.3	27.7[b]	60.5[b]	48.7	33.1[b]	20.2
Red oak	2.0	1.9	0.18	0.18	0.35	0.77	0.08[b]	0.08[b]	0.88[b]	0.95	0.28[b]	0.23[b]	38.2	55.0	504.1	512.6	34.7[b]	36.9
Cottonwood	3.2[b]	3.2[b]	0.29[b]	0.28[b]	0.98[b]	1.66[b]	0.25[b]	0.26[b]	1.38	1.10	0.56[b]	0.36	32.6	50.0[b]	192.5[b]	118.8[b]	82.8[b]	58.8
Sycamore	—	2.6	—	0.24	—	0.94	—	0.15	—	0.92	—	0.20	—	27.6	—	72.5	—	18.3

[a] $N = 9$.
[b] Significantly greater than control (0.05 level).

In the search for a species that will act as an effective nutrient sink, the characteristic of high nutrient assimilation is important. However, species undergoing irrigation are subject to increased growth rates which may cause dilution of their internal nutrient concentrations. Thus, foliar nutrient concentration should not be the sole criterion for selecting a species of superior assimilation capacity. Species capable of large biomass production should also be considered. Cottonwood combines high nutrient concentration with large biomass production and is the species exhibiting the greatest overall nutrient assimilation. Black walnut also combines these two characteristics, as do sycamore, black cherry, and Scotch pine, and all are species well suited to this treatment. Tulip poplar and Norway spruce are moderately suited to the study treatment, while red oak, white ash, and white spruce appear least suited. It should be understood that these are preliminary results.

At this time no nutrient-deficiency symptoms or toxicity have been noted. None of the species examined have accumulated B to the toxic levels reported by Neary et al. (1975). Boron, however, has undergone significantly greater assimilation by treated seedlings than by controls.

Summary

A newly established conifer-hardwood plantation received 51 mm of municipal wastewater per week over a 3-year period from 1974 through 1976. In 1975, groundwater recharge was obtained in July, August, and September. August had an unseasonably high rainfall (180 mm), which resulted in massive hydrologic loading of the site. This excessive water volume appeared to cause oxygen stress of seedlings in swale areas, excessive nutrient leaching in 1975, and dampening of the control versus treated growth differential in 1975 and 1976. Although 1976 was a drier year, groundwater recharge was still obtained from June through September.

Nutrient levels in irrigation water were low to moderate while groundwater nutrient concentrations were generally low. Nutrient renovation was adversely affected by low nutrient levels in effluent and periods of high rainfall. Phosphorus renovation exceeded 98% while that of NO_3, NH_4, total N, and Na were found to be 76.3, 75.8, 74.0, and 65.5%, respectively. Renovation for B, Mn, and Zn was virtually zero, owing to low effluent concentrations and resultant leaching.

Soil pH in 1975 was difficult to interpret, but a definite increase was observed in all horizons for the drier 1976 season. With an effluent pH of 7.7, soil reaction should continue to rise.

Soil NO_3 and total N levels increased while NH_4 levels decreased. Leaching of replaced NH_4 and the nitrification process are believed to be responsible for this. Phosphorus levels are increasing as the soil's adsorption capacity appears to be quite high and native reserves are low. Soil loss of K due to leaching occurred in 1975, but such levels have more than recovered during 1976. A similar pattern was observed for C, with present increases due to organic matter loaded with irrigation and accelerated decomposition of surface litter.

Levels of Na, although increasing in the soil, are low and are not anticipated to become troublesome on the site. The SAR of 2.27 is well within the low risk of Na increases. Calcium and Mg were affected by leaching in 1975, but showed a recovery in 1976.

Boron levels are quite variable, with an accumulation found in 1975 and a slight decline in 1976. Manganese exhibited a downward trend in 1975, but thereafter was

difficult to interpret. Soil Zn levels offered no meaningful interpretation, owing to natural soil variability.

Cottonwood, sycamore, and Scotch pine exhibit superior growth characteristics under irrigation with municipal wastewater. A larger proportion of biomass is accumulating in the stem as growth proceeds, with flushes of growth generally of longer duration extending later into the growing season. Species found to be superior with regard to total nutrient accumulation were cottonwood, black walnut, sycamore, black cherry, and Scotch pine. To date no symptoms of nutrient deficiency or toxicity are apparent.

This plantation is as yet young and these preliminary results are a function of immature root systems and incomplete site occupancy. As the seedlings mature and site utilization becomes more complete, a clearer picture regarding nutrient flow and species productivity trends should be available.

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