NUTRIENT ASSIMILATION IN TREES IRRIGATED WITH SEWAGE OXIDATION POND EFFLUENT

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ABSTRACT

Six tree species and two *Populus* hybrids were irrigated during the growing seasons from 1973 to 1976 with facultative sewage treatment pond effluent at two rates. The species and hybrids were then tested for nutrient and trace element uptake and assimilation. Generally, irrigation increased macronutrient concentrations and decreased micronutrient concentrations in the trees. Increased foliar concentrations of N, P, and K were associated with increased growth of green ash and the *Populus deltoides* x *P. nigra* hybrid, which had the greatest accumulation of all elements. Consistent reduction of several trace element concentrations were associated with increased growth of white-cedar. The portion of nitrogen removed in harvest was estimated to be 80% for dormant season harvest of whole trees and only 30% for summer harvest of main stems.

INTRODUCTION

Since legal constraints have been placed on discharging inadequately treated sewage effluents to surface water, applying treated wastewater to land has increased. Land application of treated wastewater is especially suited for communities that treat less than 1 MGD (million gallons per day) although this method of sewage disposal has been used by several larger communities that treat from 1 to 50 MGD. Frequently, the land that the wastewater is applied to is not suitable for agronomic crops but could be used to grow tree crops. Several tree species and *Populus* hybrids have already been tested and found to respond favorably with appropriate cultural practices (Cooley 1978a, Rudolph 1957, Sopper 1968). Symptoms of boron toxicity in trees irrigated with wastewater have been reported (Neary *et al.* 1975), but no associated growth losses have been detected (Cooley 1978b). Therefore, this study was conducted to find out what effect irrigation with sewage oxidation pond effluent had on nutrient and trace element uptake and accumulation by selected trees.

STUDY DESCRIPTION

The study, carried out in southwestern Lower Michigan, included two *Populus* hybrids and six other tree species planted in a gravelly morainal soil of the Boyer series, a typic hapludalf. Hardwood cuttings of 'Raverdeaux' poplar, which is a *Populus deltoides* x *P. nigra* hybrid, and seedlings of a *Populus canescens* x *P. grandidentata* hybrid, Japanese larch (*Larix leptolepis*), European larch (*L. decidua*), tulip poplar (*Liriodendron tulipifera*), and northern red oak (*Quercus rubra*) were planted in a split plot design with three replications in which irrigation rate was the main plot treatment and subplots of 25 trees were planted to different hybrids and species. 'Raverdeaux' poplar cuttings and seedlings of green ash (*Fraxinus pennsylvanica*) and northern white-cedar (*Thuja occidentalis*) were planted in a second split plot design with four replications. All selections were planted in 1972 and 'Raverdeaux' poplar was planted on a second set of plots in 1973.

Irrigated plots received effluent from a facultative sewage treatment pond at rates of 30 mm and 70 mm/week during the growing season. Comparable plots received no effluent. All plots were tilled thoroughly before planting and tilled or sprayed periodically after planting to limit regrowth of noncrop plants.

The height of each surviving tree was measured at the end of each growing season. In mid-September, 1976, 2 to 4 randomly selected sample trees from each plot were cut. Dry weights of foliage, current year's shoot growth, branches with bark, and stems with bark were obtained. Ten gram samples of each component of each sample tree were analyzed for N concentration using the micro-Kjeldahl technique and for P, K, Ca, Al, Na, Fe, Mg, Zn, Cu, Mo, Mn, and B by emission spectroscopy.[1] The N analysis was not modified to include NO_3-N and NO_2-N. Na and Mo were below detection limits of 0.05% and 10 mg/kg, respectively, in many of the samples so data could not be analyzed for treatment effect on these two elements.

SURVIVAL AND GROWTH

In 1972, rainfall was frequent and plentiful after trees were planted so irrigation had little effect on their survival. Survival ranged from 21 to 98% without irrigation and from 24 to 100% with irrigation. Only tulip poplar had significantly better survival on irrigated plots--63% with irrigation compared to 24% without irrigation. During 1973 there were periods of critical moisture stress and irrigation doubled (from 41% to 87%) the survival rate of 'Raverdeaux' poplar, which was the only selection planted in 1973.

After five growing seasons, the average height of trees planted in 1972 on nonirrigated plots ranged from about 0.5 m for northern white-cedar to nearly 4 m for 'Raverdeaux' poplar. 'Raverdeaux' poplar was 64% taller, green ash was 46% taller, and northern white-cedar was 67% taller on irrigated plots than on nonirrigated plots. The average height of other selections was greater on irrigated than on nonirrigated plots but the differences were not significant. After four growing seasons the 'Raverdeaux' poplar planted in 1973 averaged 1.8 m tall on nonirrigated plots compared to 4.9 m on irrigated plots, a difference of 169%. The difference in response of the two 'Raverdeaux'plantings (64% more height growth for 1972 plantings compared to 169% more height growth for 1973 plantings) is because of age differences, because of weather differences during their establishment, and because shoots were removed for the 1972 planting to provide cuttings for the 1973 planting.

Neither survival nor growth of any of the selections differed significantly between the two irrigation rates (Cooley 1978a).

[1] Samples were analyzed by the Research Analytical Laboratory, Dept. of Soil Science, University of Minnesota.

NUTRIENT AND TRACE ELEMENT CONCENTRATIONS AND CONTENT

The relation between irrigation and concentrations of nutrients and elements varied greatly among selections and among the different parts in most selections.

Where there were significant differences in concentrations of macronutrients in foliage, they were higher in some irrigated trees than in nonirrigated trees. Generally, there were no differences associated with different rates of irrigation (table 1). Tulip poplar had higher concentrations of calcium and magnesium only in trees irrigated with 30 mm/week. In Japanese larch the concentration of magnesium was highest in trees irrigated with 30 mm/week, lowest in nonirrigated trees, and intermediate in trees irrigated with 70 mm/week.

'Raverdeaux' poplar and green ash, two of the three selections that grew better when they were irrigated, had higher concentrations of one or more of the major macronutrients (N, P, or K) in foliage of irrigated trees. Concentrations of these elements in the other selections were not significantly different in foliage of irrigated and nonirrigated trees.

Differences were less common and more variable in concentrations of macronutrients in other parts of the tree (tables 2, 3, and 4). Nitrogen concentrations, were lower in irrigated trees than in nonirrigated trees, where there were differences. Phosphorus concentrations were higher in branches of Japanese larch and in main stems of green ash and European larch irrigated with 70 mm/week, but lower in branches of white-cedar irrigated at both rates. Concentrations of potassium, where they were significantly different, were lower in irrigated trees. Calcium concentrations were lower in shoots, branches, and main stems of white-cedar irrigated at both rates and in branches of *Populus canescens* x *P. grandidentata* and were higher in shoots of tulip poplar irrigated at 30 mm/week. Magnesium concentrations were higher in current shoots of white-cedar irrigated at both rates than in nonirrigated trees. In main stems of green ash, magnesium concentrations were lowest in trees irrigated with 70 mm/week, highest in trees irrigated with 30 mm, and intermediate in nonirrigated trees.

Significant differences in concentrations were more common for boron than for any other element. In every selection and in every part where there was a significant difference, except in current shoots on European larch, increased concentrations were associated with irrigation at one or both rates. For other trace elements, lower concentrations were usually associated with irrigation at one or both rates--except iron in current shoots on 5-year-old 'Raverdeaux' poplar and zinc in main stems of green ash.

Table 1. Average nutrient concentration in foliage. Values for species and elements followed by different letters are significantly different at the 90% probability level or more.

Selection	Irrigation (mm/wk)	TKN	P	K	Ca	Mg	Al	Fc	Zn	Cu	Mn	B
		percent					ppm					
'Raverdeaux' poplar												
4 year old	0	2.40a	0.22a	1.18a	2.04a	0.67a	63a	184a	123a	10a	135a	79a
	30	3.02a	0.29a	2.12b	1.83a	0.40a	66a	252a	88a	11a	150a	156b
	70	2.91a	0.30a	1.80b	1.90a	0.43a	68a	209a	142a	8a	135a	211c
5 year old	0	1.90a	0.20a	1.43a	1.25a	0.45a	78a	167a	97a	6a	195a	74a
	30	2.33b	0.34b	1.92a	1.89b	0.42a	66a	175a	62a	8a	117a	175b
	70	2.29b	0.34b	2.30a	1.96b	0.48a	63a	150a	123a	8a	114a	178b
Green ash	0	1.81a	0.20a	0.78a	1.18a	0.31a	91a	215a	19a	12a	39a	24a
	30	1.96a	0.28b	1.53b	1.29a	0.34a	93a	243a	22a	14a	43a	42b
	70	2.10a	0.35b	1.41b	1.29a	0.38a	79a	195a	27a	10a	40a	36b
Northern white-cedar	0	1.55a	0.23a	0.55a	1.86a	0.15a	248a	348a	37a	5a	146a	23a
	30	1.60a	0.22a	0.75a	1.75a	0.31b	198b	303a	28b	5a	98b	54b
	70	1.57a	0.24a	0.67a	1.50a	0.27b	199b	329a	30b	5a	59c	45b
Populus canescens x *P. grandidentata*	0	2.25a	0.25a	0.68a	2.14a	0.32a	185a	340a	207a	10a	174a	72a
	30	1.92a	0.30a	0.97a	2.28a	0.55b	147a	219a	167b	8a	142b	152b
	70	2.24a	0.31a	1.22a	2.00a	0.54b	154a	248a	88c	8a	71c	154b
Japanese larch	0	1.94a	0.41a	0.83a	0.51a	0.21a	190a	287a	43a	7a	121a	88a
	30	1.91a	0.52a	1.42a	1.20a	0.37c	180a	298a	51a	6a	155a	153a
	70	2.63a	0.22a	1.32a	0.64a	0.29b	97a	172a	32b	3a	35a	99a
European larch	0	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
	30	1.44a	0.37a	1.28a	0.95a	0.40a	127a	226a	45a	4a	58a	198a
	70	2.22a	0.35a	1.04a	0.81a	0.37a	156a	252a	48a	4a	63a	131a
Tulip poplar	0	1.90a	0.23a	1.26a	1.33a	0.34a	184a	98a	26a	9a	132a	42a
	30	1.83a	0.27a	1.02a	2.23b	0.63b	122b	135a	19a	7a	99b	138b
	70	2.20a	0.25a	1.65a	1.43a	0.45a	90c	148a	20a	7a	32c	106b
Northern red oak	0	1.82a	0.20a	0.87a	1.06a	0.38a	106a	179a	43a	4a	297a	73a
	30	1.90a	0.24a	0.78a	1.35a	0.39a	126a	210a	45a	6a	252a	133a
	70	2.01a	0.22a	0.88a	1.10a	0.37a	98a	169a	37a	5a	90a	125a

[1] No samples of European larch foliage were analyzed.

Table 2. Average nutrient concentration in current shoot growth. Values for species and element followed by different letters are significantly different at the 90% probability level or more.

Selection	Effluent (mm/wk)	TKN	P	K	Ca	Mg	Al	Fe	Zn	Cu	Mn	B
		percent					ppm					
'Raverdeaux' poplar												
4 year old	0	0.86a	0.16a	0.79a	0.79a	0.18a	29a	39a	73.9a	6.0a	31.3a	19.6a
	30	0.76a	0.16a	0.66a	0.91a	0.15a	21a	33a	46.4a	4.7a	27.4a	15.6a
	70	0.89a	0.16a	0.70a	1.07a	0.19a	24a	32a	32.4a	3.4a	22.4a	15.9a
5 year old	0	0.83a	0.16a	0.50a	1.03a	0.23a	28a	50a	47.1a	4.8a	30.2a	14.9a
	30	0.99a	0.21a	0.82b	1.28a	0.22a	46a	124b	47.2a	9.8a	43.6a	18.0a
	70	0.63a	0.14a	0.43a	0.92a	0.17a	26a	29a	44.6a	8.1a	24.9a	12.3a
Green ash	0	0.76a	0.10a	0.45a	0.56a	0.10a	21a	42a	23.1a	17.7a	13.7a	14.2a
	30	0.66a	0.12a	0.58a	0.59a	0.11a	24a	106a	25.8a	28.4a	17.0a	25.2b
	70	0.82a	0.13a	0.56a	0.60a	0.11a	21a	103a	26.7a	15.8a	13.0a	26.2b
Northern white-cedar	0	0.74a	0.15a	0.63a	1.65a	0.10a	232a	245a	35.0a	6.8a	56.1a	18.0a
	30	0.71a	0.14a	0.55a	1.12b	0.16b	154b	163b	24.7a	8.4a	24.1b	27.7a
	70	0.66a	0.12a	0.57a	1.17b	0.16b	182b	227a	27.1a	8.4a	17.6b	24.3a
Populus canescens x *P. grandidentata*	0	1.24a	0.21a	0.63a	1.55a	0.15a	49a	60a	90.5a	9.0a	29.3a	17.5a
	30	0.92a	0.18a	0.53a	1.38a	0.16a	35b	43a	100.2a	9.1a	22.6a	23.5b
	70	1.02a	0.19a	0.52a	1.06a	0.15a	30b	49a	71.7a	9.2a	11.4a	22.4b
Japanese larch	0	0.85a	0.18a	0.93a	0.32a	0.10a	71a	80a	28.1a	7.3a	75.2a	30.9a
	30	0.77a	0.17a	0.76a	0.36a	0.11a	86a	95a	38.3a	13.7a	154.8a	26.7a
	70	1.04a	0.17a	0.66a	0.24a	0.08a	56a	50b	29.6a	7.4a	106.9a	25.0a
European larch	0	1.48a	0.18a	0.90a	0.29a	0.08a	65a	76a	34.6a	5.3a	196.7a	31.7a
	30	0.74a	0.17a	0.76a	0.40a	0.10a	73a	126a	27.1a	9.8a	59.5a	24.4b
	70	0.85a	0.17a	0.80a	0.31a	0.10a	72a	82a	38.8a	9.4a	80.8a	22.2b
Tulip poplar	0	0.74a	0.11a	0.62a	0.52a	0.12a	84a	31a	14.4a	8.3a	43.6a	14.0a
	30	0.54a	0.12a	0.57a	0.63b	0.17a	21b	23a	30.5a	9.5a	21.4b	21.3a
	70	0.63a	0.14a	0.68a	0.48a	0.12a	15b	20a	17.9a	5.6b	10.8b	15.0a
Northern red oak	0	0.50a	0.13a	0.36a	1.03a	0.21a	53a	51a	34.7a	5.9a	248.3a	21.6a
	30	0.56a	0.14a	0.34a	1.11a	0.21a	51a	47a	33.5a	4.6a	227.3a	22.8a

Average nutrient concentration in branches. Values for species and element followed by different letters are significantly different at the 90% probability level or more.

Selection	Effluent (mm/wk)	TKN	P	K	Ca	Mg	Al	Fe	Zn	Cu	Mn	B
		percent					ppm					
'Raverdeaux' poplar												
4 year old	0	0.58a	0.10a	0.42a	0.65a	0.08a	44a	35a	66.4a	6.6a	18.6a	11.8a
	30	0.49a	0.12a	0.52a	0.82a	0.10a	34a	25a	34.4a	4.4a	16.8a	13.2a
	70	0.66a	0.10a	0.52a	0.71a	0.09a	37a	26a	19.4a	3.0a	15.3a	13.6a
5 year old	0	0.58a	0.11a	0.30a	0.85a	0.12a	38a	32a	44.0a	3.4a	20.6a	10.4a
	30	0.48a	0.08a	0.26a	0.60a	0.07a	34a	81a	19.6a	12.3a	11.2b	9.9a
	70	0.37a	0.12a	0.48a	0.60a	0.11a	31a	29a	42.1a	5.4a	19.3a	12.5a
Green ash	0	0.54a	0.07a	0.22a	0.66a	0.08a	36a	49a	32.0a	42.3a	12.2a	15.5a
	30	0.44a	0.06a	0.23a	0.66a	0.08a	39a	78a	29.0a	54.6a	21.6a	21.7a
	70	0.59a	0.07a	0.27a	0.65a	0.08a	36a	76a	25.0a	16.4a	16.8a	21.2a
Northern white-cedar	0	0.56a	0.12a	0.38a	1.69a	0.07a	309a	333a	41.6a	7.4a	53.3a	12.0a
	30	0.52a	0.08b	0.34a	1.08b	0.07a	80b	79b	28.8b	7.1a	15.3b	16.4a
	70	0.48a	0.08b	0.34a	1.09b	0.07a	99b	104b	27.6b	6.8a	10.5b	14.6a
Populus canescens x *P. grandidentata*	0	0.55a	0.11a	0.39a	1.26a	0.08a	42a	26a	89.5a	10.8a	15.8a	12.1a
	30	0.66a	0.14a	0.43a	1.08b	0.10a	56a	31a	90.0a	11.7a	15.9a	17.3b
	70	0.53a	0.10a	0.40a	1.02b	0.08a	43a	22a	58.2a	10.2a	10.0a	15.7b
Japanese larch	0	0.64a	0.11a	0.34a	0.41a	0.08a	202a	227a	38.2a	8.1a	151.5a	13.7a
	30	0.53a	0.10a	0.32a	0.39a	0.07a	125b	126b	41.4a	14.0a	167.3a	17.6a
	70	0.54a	0.16b	0.34a	0.33a	0.07a	83b	76b	21.0a	5.2a	14.4a	17.4a
European larch	0	0.51a	0.12a	0.43a	0.60a	0.11a	152a	151a	44.0a	7.2a	57.8a	26.2a
	30	0.50a	0.11a	0.29a	0.38a	0.08a	101a	87a	31.9a	8.6a	22.2a	22.3a
	70	0.64a	0.11a	0.32a	0.43a	0.09a	176a	178a	53.0a	19.2a	52.8a	25.4a
Tulip poplar	0	0.64a	0.10a	0.36a	0.58a	0.12a	154a	46a	27.2a	8.2a	57.8a	15.2a
	30	0.40b	0.08a	0.36a	0.46a	0.10a	58b	20b	16.1a	7.9a	10.7b	15.9a
	70	0.46b	0.06a	0.33a	0.55a	0.12a	33b	24b	16.5a	5.7a	13.6b	15.8a
Northern red oak	0	0.39a	0.09a	0.24a	1.02a	0.16a	48a	102a	33.3a	6.9a	178.5a	16.8a
	30	0.43a	0.10a	0.24a	1.06a	0.17a	37a	34a	24.1a	4.1a	170.9a	20.5a
	70	0.43a	0.08a	0.20a	0.93a	0.15a	32a	16a	32.0a	9.1a	63.2b	22.0a

Table 4. Average nutrient concentration in main stems. Values for each species and element when followed by different letters are significantly different at the 90% probability level or more.

Selection	Effluent	TKN	P	K	Ca	Mg	Al	Fe	Zn	Cu	Mn	B
	(mm/wk)	- - - - - - -	- - - - percent	- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -	- - - - ppm	- - - - - - -	- - - - - - -	- - - - - - -
'Raverdeaux' poplar												
4 year old	0	0.48a	0.10a	0.22a	0.69a	0.12a	25a	51a	37.6a	5.4a	20.5a	8.6a
	30	0.30a	0.08a	0.20a	0.28a	0.05a	16a	59a	21.8a	8.0a	12.3a	6.0a
	70	0.34a	0.10a	0.31a	0.52a	0.09a	15a	20a	41.4a	8.5a	12.8a	9.1a
5 year old	0	0.58a	0.10a	0.36a	0.65a	0.11a	41a	35a	66.0a	8.2a	23.3a	11.6a
	30	0.41a	0.10a	0.23a	0.40a	0.08a	16a	20a	30.5a	4.1a	10.1b	7.6a
	70	0.34a	0.08a	0.22a	0.28a	0.06a	15a	20a	16.3a	2.0a	10.0b	7.4a
Green ash	0	0.44a	0.06a	0.20a	0.38a	0.06b	21a	36a	12.2a	28.8a	([1])	11.3a
	30	0.32b	0.05a	0.20a	0.28a	0.05a	18a	32a	10.4a	20.9a	([1])	13.6a
	70	0.47a	0.08b	0.26b	0.46a	0.07c	18a	54a	19.1b	13.1a	([1])	18.6b
Northern white-cedar	0	0.56a	0.08a	0.31a	1.49a	0.05a	223a	234a	37.1a	7.3a	42.6a	9.0a
	30	0.52a	0.07a	0.32a	0.86b	0.06a	52b	50b	23.9b	7.7a	12.3b	11.8a
	70	0.48a	0.07a	0.26a	0.79b	0.04a	38b	36b	23.6b	8.6a	([1])	9.3a
Populus canescens x *P. grandidentata*	0	0.56a	0.10a	0.36a	0.96a	0.07a	37a	30	85.2a	10.9a	11.3a	7.7a
	30	0.58a	0.10a	0.32a	0.73a	0.07a	30a	([1])	64.4a	10.5a	10.5a	12.1a
	70	0.42a	0.07a	0.24a	0.48a	0.05a	16a	([1])	40.3a	5.6a	([1])	8.6a
Japanese larch	0	0.39a	0.08a	0.24a	0.23a	0.05a	56a	89a	25.8a	7.2a	89.7a	8.6a
	30	0.37a	0.10a	0.39a	0.23a	0.06a	30a	54a	41.6a	17.0a	103.3a	12.2b
	70	0.32a	0.09a	0.41a	0.16a	0.05a	20a	([1])	16.5a	5.6a	15.9a	12.7b
European larch	0	0.48a	0.09a	0.26a	0.21a	0.05a	53a	46a	32.8a	13.4a	113.0a	11.1a
	30	0.32a	0.08a	0.23a	0.19a	0.06a	29a	49a	36.6a	19.1a	22.4b	12.0a
	70	0.36a	0.17b	0.41a	0.18a	0.07a	26a	28a	45.6a	19.0a	31.6b	16.1a
Tulip poplar	0	0.52a	0.07a	0.38a	0.44a	0.09a	96a	24a	16.0a	7.6a	38.0a	10.6a
	30	0.33a	0.07a	0.37a	0.35a	0.09a	19b	26a	18.8a	7.9a	13.8b	11.8a
	70	0.47a	0.11a	0.44a	0.45a	0.11a	22b	30a	14.1a	6.3a	([1])	13.6a
Northern red oak	0	0.32a	0.10a	0.21a	0.84a	0.14a	32a	33a	21.2a	6.3a	140.8a	12.8a
	30	0.37a	0.11a	0.17a	0.09a	0.13a	30a	23a	15.5a	4.9a	124.8a	14.9a
	70	0.32a	0.08a	0.20a	0.55a	0.11a	19a	([1])	13.8a	4.3a	33.3b	14.4a

[1] All values below

Table 5. Nutrient and trace metal content per tree.

Selection	N	P	K	Ca	Mg	Al	Fe	Zn	Cu	Mn
	- - - - - - - grams - - - - - - -					- - - - - - - - - mg - - - - - - - - -				
'Raverdeaux' poplar										
4 year old	15.4	2.6	13.4	15.0	3.0	74.9	119.7	99.7	11.3	77.7
5 year old	65.5	12.8	48.8	67.4	12.4	276.3	669.1	421.2	88.4	282.2
Populus canescens x *P. grandidentata*	24.2	4.2	14.2	31.3	4.4	151.5	131.4	358.4	28.6	89.6
Japanese larch	17.9	3.6	12.6	9.0	2.6	181.3	238.0	73.5	21.2	191.1
Green ash	14.9	2.3	10.3	10.8	2.5	65.2	167.9	29.1	25.0	28.1
Tulip poplar	11.0	1.6	8.2	12.1	3.2	67.5	74.4	20.0	7.8	49.1
European larch	5.4	1.2	3.8	3.0	1.0	66.8	83.4	29.8	9.6	29.8
Northern white-cedar	4.7	0.8	0.8	5.5	1.0	60.8	89.7	11.2	2.5	25.7
Northern red oak	1.8	0.4	0.9	1.7	0.8	11.6	15.8	5.6	1.1	25.3

In most selections, the concentrations of any one trace element did not vary consistently in more than two parts. In white-cedar, however, aluminum and manganese concentrations were lower in all parts of trees irrigated at both rates, calcium and iron concentrations were lower in all parts except foliage, zinc concentrations were lower in all parts except shoots, and magnesium concentrations were higher in foliage and current shoots.

Growth rate was the primary determinant of nutrient and trace element accumulation. Ranked according to the average dry weight of 5-year-old trees on irrigated plots 'Raverdeaux' poplar > *Populus canescens* x *P. grandidentata* > Japanese larch > green ash > tulip poplar > European larch > northern white-cedar > northern red oak. Rank based on amount of nitrogen and phosphorus, would be exactly the same (table 5) and only one or two changes would be necessary for ranks based on each of the other elements.

NITROGEN UPTAKE AND ACCUMULATION

The rate at which plants take up and accumulate nitrogen is particularly important in managing slow rate wastewater irrigation on sandy soils because the more nitrogen the trees accumulate, the less nitrogen is leached to groundwater. 'Raverdeaux' poplar accumulated more nitrogen than any of the other selections tested, so a more detailed examination of the data for this hybrid will provide a relevant comparison with other crop alternatives along with some guidelines for managing tree crops to minimize nitrate leaching.

The nitrogen content of 'Raverdeaux' poplar was 15.4 grams in 4-year-old trees and 65.5 grams in 5-year-old trees . For the experimental plantings with 5,760 trees/ha, this 50 gram/tree difference in the fifth growing season amounted to 288 kg/ha. This is 36% more than the uptake reported for 3-year-old lombardy poplar (*Populus nigra* irrigated with wastewater in Washington (Cole and Schiess 1978).

In mid-September leaves on 5-year-old trees contained 27.8 grams of nitrogen per tree or approximately 160 kg/ha. This was prior to any substantial movement out of the leaves, so it is reasonable to expect that half of this nitrogen would have been transferred to other parts of the trees before the leaves dropped (Kramer and Kozlowski 1960). The total accumulation, 288 kg/ha, reduced by half of the amount in foliage, 80 kg/ha, is the amount accumulated in stem, branches, and shoots during the fifth growing season, 208 kg/ha. This is greater than the maximum seasonal uptake reported for corn in several experimental applications of wastewater and greater than uptake by reed canary and several other forage grasses that received similar amounts of nitrogen in wastewater (Clapp *et al.* 1978). Because it is mainly a function of increased volume, and volume usually increases at an increasing rate in young stands, it seems possible that the annual accumulation may be sustained at this level or increase.

This estimate of annual nitrogen accumulation greatly exceeds the amount of nitrogen applied in irrigation water even at the 70 mm/week rate. However, the total amount of nitrogen accumulated in the first 4 years was only 89 kg/ha while 176 kg/ha was applied where trees were irrigated with 30 mm/week and 412 kg/ha was applied where they were irrigated with 71 mm. Some of this excess was probably stored in soil constituents and in noncrop plants. As tree crowns expanded, noncrop plants were crowded out and the nutrients in them became available. Thus the noncrop plants helped reduce leaching of nitrates to groundwater and provided a source of nutrients when the requirements of the trees exceeded the current applications.

The parts of the tree that are harvested and removed from the site and the time of harvest will determine how much of the accumulated nitrogen will be removed. All of it will be removed only, if whole trees, including leaves, are harvested when leaves are fully developed. If whole trees are harvested during the dormant season, about 80% of the accumulated nitrogen would be removed. Harvesting only stems would remove about 30%.

CONCLUSIONS

Irrigation with wastewater affected concentrations of different elements in each species and hybrid tested but the affect was usually similar for any given element. In selections where foliar concentrations of macronutrients in nonirrigated and irrigated trees were different, irrigated trees usually had higher concentrations. In selections where concentrations of trace elements other than boron were different, irrigated trees usually had lower concentrations.

In 5 of the 8 selections foliar boron concentrations were higher in irrigated trees yet there were no visible symptoms of boron toxicity. All of the selections that grew better when they were irrigated had elevated boron concentration in foliage. Only two of the selections that did not grow better with irrigation were affected. In 'Raverdeaux' poplar and green ash, increased foliar concentrations of one or more macronutrients were associated with increased growth. White-cedar also grew better when it was irrigated and the lower trace element concentrations associated with irrigation were more consistent among its components than among components of any other selection.

The greatest accumulation of nutrients and trace elements was found in 'Raverdeaux' poplar, primarily because the trees were larger than any of the others. Its' estimated annual uptake of nitrogen, approximately 200 kg/ha, compared favorably with that reported for agronomic crops that received similar applications of nitrogen in wastewater.

During the first 4 years after trees were planted, nitrogen applications exceeded uptake and nitrogen retention depended on storage in soil and noncrop plants. In the fifth year, uptake exceeded application and the stored nitrogen made up some of the deficit. Thus soil and noncrop plants help buffer fluctuations in uptake by crop plants.

The amount of accumulated nitrogen removed from the site at harvest may vary from 30% to 100%. Complete removal may not always be feasible because it involves harvesting leaves as well as woody parts of the tree. Harvesting whole trees during the dormant season will remove 80% of the accumulated nitrogen.

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