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The Nutrient Pool of Five Important Bottomland Hardwood Soils

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SUMMARY

Heretofore, with the exception of N, the concentration of total nutrients and the amount of variation in nutrient concentrations among and within soil series and depths within the rooting zone of forested alluvial soils of the South was unknown. Information about total nutrient concentrations is important in studying the danger of nutrient depletion posed by total tree harvest and other forms of intensive management. In this study, five important alluvial forest soils were sampled on each of five sites, and the samples were analyzed for total N, P, K, Mg, and Ca. Available nutrient levels were determined as well. Soil series was a significant source of variation for all nutrients ($p = 0.95$). Nutrient concentration varied significantly among sites within soil series in most cases. Total N, P, and Mg also varied by depth. The available nutrient concentrations of all five nutrients were significantly correlated with their respective total nutrient concentrations. These alluvial soils are high in nutrients; potassium content is particularly high (8-19 g/kg). Nutrient depletion resulting from withdrawals of nutrients in whole-tree harvests will not occur for several rotations in the soils tested. However, to reduce the risk of depletion of sites with unexpectedly low nutrient reserves, the soil should be tested, and when needed, maintenance fertilizer should be applied or less intensive harvests prescribed.

Keywords: total nutrients, available nutrients, alluvial soils, nutrient depletion, soil series.

INTRODUCTION

Whole-tree chipping and other forms of intensive harvest remove considerable quantities of nutrients from forest sites (Hornbeck and Kropelin 1982). Destruction of the vegetative cover and disturbance of the soil surface may temporarily accelerate nutrient loss in runoff and percolating waters (Vitousek and Reiners 1975). The question "Will intensive harvests and disturbance of bottomland hardwood sites deplete their soils of essential nutrients?" needs to be answered. To do so, we not only need information on nutrient concentration in runoff water and estimates of harvest withdrawals, we must also document nutrient reserves in bottomland sites.

Nutrient reserves can be classified into two forms, available (or exchangeable) and fixed. The trees accumulate their nutrient load from the available pool of nutrients. The available pool is in equilibrium with and can be slowly recharged from the insoluble or fixed pool. The nutrient depletion question cannot be fully answered unless the content of total nutrients is known. Analyses of available nutrient concentrations in a number of forested alluvial soils of the South have been published (Broadfoot 1978). Of the total nutrient reserve (available plus fixed forms), only N was documented. Base-line data for detection of changes in total nutrient reserves over time and disturbance did not exist.

This study was undertaken to measure the total nutrient reserves of five important bottomland forest soils. Each soil represented a distinct environment so that the study would represent as much of the bottomland hardwood ecosystem of the South as possible. The variation within and among sites and between depths was tested, and total nutrient concentrations were related to available nutrient levels.

MATERIALS AND METHODS

All the soils sampled are alluvial and covered with timber; old-field sites were not considered. Three of the soils were deposited by the Mississippi River: the Alligator series (very fine, montmorillonitic, acid, thermic Vertic Haplaquepts) is a clay; the Bruno series (sandy, mixed,

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thermic Typic Udifluvents) is a loamy sand; and the Commerce series (fine-silty, mixed, **nonacid,** thermic **Aeric** Fluvaquents) is medium textured. The Falaya series (coarse-silty, mixed, acid, thermic **Aeric Flu**-vaquents) is a silt or silt loam on flood plains of streams in the Silty Uplands. The Mantachie series (fine-loamy, siliceous, acid, thermic **Aeric** Fluvaquents) is a **medium-**textured soil of the Coastal Plain. A soil was identified in the field by establishing its soil taxinomic classification and then matching it with the appropriate series description. Samples of these soils were collected in early summer in portions of Mississippi, Arkansas, and Louisiana.

Each series was represented by five forested sites located at least 8 km apart. At each site, three locations spaced 30 m apart were chosen for sampling. At each location, two auger holes were bored 3 m apart and the soil in each collected from depths of O-30.5 cm and **30.5–61** cm. This resulted in a total of 300 soil samples, which were air-dried and sieved (2 mm).

All samples were analyzed for total N, P, K, Mg, and Ca. Total N was determined by the standard Kjeldahl procedure (Bremner and Mulvaney 1982). Total P was determined by a **NaOH** fusion technique described by Smith and Bain (1982). Potassium, Mg, and Ca were measured by atomic absorption spectroscopy **(AAS)** from the **NaOH-fused** sample from the total P procedure after dilution and acidification. Commercially available reference soils were employed as standards.

Because of limitations of time and expense, available nutrient concentrations were determined for only the samples from the upper 30.5cm depth. Available N (principally inorganic) was extracted from soil samples with acidified **NaCl,** the NO_3^- being converted to NH_4^+ through the use of Davarda's alloy according to a procedure described by Jackson (1958). Available P was determined with a procedure involving two-stage dilute HCI and acidic acid extraction (Soil Test Work Group 1974). Exchangeable K, Mg, and Ca were extracted with 1 ***N*** NH_4OAc and measured by **AAS.**

To help direct future sampling and potentially **nutrient-**depleting harvest activities, sources of variation of total nutrients in these alluvial soils were evaluated by the analysis of variance technique (p = 0.95). Split-plot and nested arrangements were used. When tests proved significant, soil depths and means of nutrient concentrations for soil series were compared by Duncan's New Multiple Range test. In addition, the relationships between available and total nutrient concentrations in the upper 30.5 cm were related by linear regression.

RESULTS

The average total nutrient concentration in the five soil series for O-30.5 cm and 30.5-61 cm are listed in table 1. The concentrations varied from more that 1 percent K to less than 0.1 percent P. An approximate total nutrient content per hectare for the upper 61 cm of soil can be obtained by multiplying total nutrient concentration by 8.966 million kilograms, an average figure of soil weight per hectare **(Buckman** and Brady 1960). Averages for each soil and nutrient are presented in table 2.

Soil series was a significant source of variation for all five nutrients. In table 2, multiple comparisons of means indicate significant ranking according to concentration in the soil. The series were generally ranked in order of decreasing concentration: Alligator, Commerce, Bruno, Falaya, and Mantachie. The three Mississippi River alluvial soils, Alligator, Commerce, and Bruno, usually had greater concentrations than upland and coastal plain

Table 1 .-*Average total nutrient **concentrations** in five soil series at two depths*

Nutrient	Depth	Alligator	Bruno	Commerce	Falaya	Mantachie
	Cm			*G per kg*		
N	0-30.5	**2.18±0.50***	**0.83±0.34**	**0.94±0.16**	**0.87±0.26**	**0.85±0.22**
	30.5–61	1.60-co.47	**0.24±0.15**	**0.65±0.25**	**0.56±0.16**	**0.44±0.11**
P	0-30.5	**0.83±0.09**	**0.61±0.10**	**0.72±0.07**	**0.41±0.12**	**0.31±0.05**
	30.5–61	0.7420.09	**0.54±0.06**	**0.69±0.07**	**0.38±0.11**	**0.28±0.08**
K	0-30.5	**19.05±0.68**	**16.88±1.02**	**18.35±0.62**	**11.69±3.28**	**8.03±2.25**
	30.5-61	**18.97±0.66**	**16.68±0.79**	**18.54±0.79**	**11.26±3.03**	**8.22±2.42**
Ca	0-30.5	**6.37±0.60**	**8.74±1.48**	**7.87±1.15**	1.48k0.76	**0.73±0.38**
	30.5–61	**6.23±0.50**	**10.08±1.16**	**8.17±1.65**	**1.21±0.63**	**0.75±0.62**
Mg	0-30.5	**10.51±0.85**	**4.89±1.47**	**6.66±0.23**	**2.03±0.77**	**1.81±0.62**
	30.5-61	**10.96±0.81**	**5.61±1.10**	**7.16±0.85**	1.91k0.68	**2.19±0.85**

***Mean±standard** deviation.

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Table 2.-*Approximate weights of total nutrients in the upper 61 cm in five soil series* *

Nutrient	Alligator	Bruno	Commerce	Falaya	Mantachie	EMS
	Mg per hectare					
N	16.1a	4.8b	7.1b	6.4b	5.8b	0.0297
P	7.1a	5.2b	6.3a	3.6c	2.7c	0.0065
K	170.5a	150.4a	165.3a	102.9b	72.9b	6.0299
Ca	57.4c	84.4a	72.0b	12.1d	6.6d	1.0645
Mg	96.3a	47.1b	62.0a	17.7c	17.9c	1.0801

*Means within a row followed by the same letter are not significantly different at the 0.05 level.
EMS = Error mean square.

Table 3.-*Comparison of means of total nutrient concentrations by depth* .

Nutrient	Depth		EMS
	O-30.5 cm	30.5–61 cm	
	G per kg		
N	0.111a	0.070b	0.00087
P	0.058a	0.053b	0.00003
K	1.480a	1.473a	0.00143
Ca	0.508a	0.529a	0.00469
Mg	0.518b	0.557a	0.00139

*Means within a row followed by the same letter are not significantly different at the 0.05 level.
EMS = error mean square.

alluvial soils. Concentrations of total nutrient by depth averaged across the five soil series are given in table 3. Depth was significant for N, P, and Mg but insignificant for K and Ca. Although N, P, and Mg differed significantly by depth, the difference in concentration by depth was large (63 percent) for N only. There were no significant series x depth interactions.

Sampling site was a significant source of variation in most of the series-nutrient combinations. This indicates significant variation in total nutrient concentrations within most soil series. As would be expected, there was less variation within sites than between them-more than half the F tests for location within site were not significant.

In table 4, mean available nutrient concentrations of the five elements are presented and compared. Available nutrients varied significantly among soil series. In general, the series were ranked as they were for total nutrient levels. Available nutrient supply varied from about 1 percent of the total N in the soil to about 80 percent of the total Ca. Approximate available nutrient weight as kilograms per hectare (30.5 cm layer) may be obtained by multiplying the numeric value of available nutrient concentration by 4.48. It varied from 38 to 66 kilograms of N per hectare to 2 to 24 thousands of kilograms of Ca per hectare.

The five total nutrient concentrations were significantly correlated with their respective available nutrient concentrations in the upper 30.5 cm of soil. Regressing total nutrient concentrations on available nutrient concentrations and their square yielded coefficients of multiple determination (R^2) values ranging from 0.28 for N to 0.88 for Mg (table 5). Thus total nutrient levels for these soils may be predicted from available nutrient concentrations if no other means is available.

DISCUSSION AND CONCLUSIONS

Massive amounts of K, Ca, and Mg were present in all the soil samples analyzed. Substantial amounts of N and P were also present. Soils deposited by the Mississippi River were higher in K, Ca, and Mg than the Coastal Plain or Silty Upland alluvial soils. This did not always hold true for N and P. Despite its loamy sand texture, Bruno soil contained surprising amounts of total nutrients. This may be a result of periodic flooding by the mildly alkaline waters of the Mississippi River. There were not only differences in total nutrients among soil series, but also considerable differences among sites within the same series. This, no doubt, reflects the extreme variability of the alluvial deposits layed down by the river over the years. Liberal sampling of these alluvial soils is indicated to assure accurate conclusions about nutrient properties.

Depth was not as important as expected. Concentrations of K and Ca were not different between depths. Although total P and Mg concentrations at both depths

Table 4.—*Comparison of means of available nutrient concentrations by soil series'*

Nutrient	Alligator	Bruno	Commerce	Falaya	Mantachie	EMS
			G per mg			
N	14.84a	8.44b	10.62ab	13.08ab	9.60b	10.6
P	49.3a	49.9a	60.9a	18.3b	11.7b	210.0
K	402.5a	143.2c	223.2b	58.44	48.4d	2953
Ca	5246a	1669c	3254b	508d	404d	246765
Mg	1302a	306c	656b	183c	153c	26662

'Means within a row followed by the same letter are not significantly different at the 0.05 level.
EMS = error mean square.

Table 5.—*Regression of total nutrient levels (T) on available nutrient levels (A) for the five nutrients tested in the upper 30.5 cm of soil*

Nutrient	Equation*	R^2	CV
N	$T = 0.2892 + 0.07062A + 0.0003029A^2$	0.2622	44.71
P	$T = 0.19660 + 0.014491A + 0.0008728A^2$	0.7668	17.46
K	$T = 7.4570 + 0.07263A + 0.0001038A^2$	0.7075	17.26
Mg	$T = 1.3097 + 0.008600A + 0.000001A^2$	0.6760	23.58
Ca	$T = 0.7023 + 0.003968A + 0.0000005A^2$	0.5974	42.86

*Values for T and A are g/kg of nutrient in the upper 30.5 cm of soil.

were significantly different, the actual magnitude of the difference was small and probably unimportant. Total N was considerably more concentrated in the upper 30.5 cm than in the lower 30.5 cm. This was a result, no doubt, of a higher concentration of organic matter and of fixation and cycling in the more biologically active surface 30.5 cm. Leaching seems to have done little to stratify these recent alluvial soils. The loss of surface layers of soil by erosion or scalping may not carry such long-term nutrient effects as in more weathered soils. Also, due to the small vertical nutrient stratification, sampling depth for total nutrients may not be as critical as in other soils.

Although the available nutrients P, K, and Mg are available in only a fraction of the amount of the total nutrients, enough of each is present in southern bottomland soils for good growth, as evidenced by the lack of deficiency symptoms and response in fertilizer trials (Francis 1985). Response to N fertilization most often occurs in old-field stands where much of the organic matter with its nitrogen has been lost.

Nutrients potentially withdrawn by whole-tree harvest of bottomland hardwoods on very short rotations can exceed nutrients added by rainfall and other sources by a few kilograms per hectare per rotation (Blackmon 1979; Francis and Baker 1982; Francis 1984). This withdrawal could, over many rotations, reduce both the available and fixed pools of nutrients and lead to deficiencies and reduced growth. The average weights of nutrients that were removed by a simulated summer-whole tree harvest from five bottomland hardwood stands with sawlog-size trees were: N, 369 kg/ha; P, 37 kg/ha; K, 202 kg/ha; Ca, 783 kg/ha; and Mg, 70 kg/ha[1]. Of these nutrients, only the withdrawal of Ca exceeded the accumulated nutrient additions in local rainfall (Lockaby 1981) over a 75-year rotation, and this by 319 kg/ha. Nothing is known about losses or gains from periodic floodwaters. The species mix and character of the vegetation harvested would certainly influence the rate of removal of nutrients. However, several rotations would certainly be required before deficiencies would be felt on even the poorest sites sampled. This is a small sample of the numerous alluvial soils in the South, and it is likely that soils exist, especially in the Coastal Plain, that are lower in nutrient reserves than these reported. Before intensive harvests are commenced, a soil test of at least exchangeable Ca should be done. When nutrient reserves are encountered that do not far exceed the quantities expected to be removed, either a less intensive harvest regime should be employed or a fertilizer maintenance program prescribed.

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