Pine

VECTOR ANALYSIS IDENTIFY LOBLOLLY PINE (*PINUS TAEDA* L.) PHOSPHORUS DEFICIENCY ON A BEAUREGARD SOIL'

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Abstract-We studied the response of densely stocked one-year-old loblolly pine (*Pinus taeda* L.) to N and P fertilizers on a Beauregard silt loam (fine silty, siliceous, thermic, Plinthaquic Paleudults). A "continuous function" experimental design with three replications was used. Each replication consisted of 12 m X 12 m plots, with three trees planted within a square meter area for each treatment. Ten levels each of N and P were applied. Application rates ranged from: 0 to 240 Kg ha-' N, and 0 to 900 Kg ha" P. Potassium was applied at a uniform rate of 50 Kg ha". Phosphorus and K application rates were based upon adsorption isotherms, while N application rates were based upon a previous study on the same soil. Vector analysis provides an opportunity to simultaneously compare plant growth, nutrient concentration and nutrient content on one graph. Vector analysis revealed that P application increased P concentration, P content and dry weight showing unfertilized trees were deficient in P. Nitrogen-only application had an antagonistic effect on P by decreasing P concentration, P content and dry weight. Enhanced growth was observed when both N and P were applied in combinations.

INTRODUCTION

Fertilizer application has been shown to significantly enhance the productivity of forest stands on soils where nutrients have become deficient and limit growth (Pritchett 1979, Shoulders and Tiarks 1990, Vann 1984). Its effect is more pronounced on young trees when the fertilization program is targeted to overcome nutrient deficiencies during early growth stages (Torbert and Burger 1984). The rationale is that young trees have greater nutrient demand than mature trees. When a tree is fully grown, most of the nutrient demands for growth will be met by nutrient cycling and within tree translocation (Bowen and Nambiar 1984, Vann and Brooks 1983). Therefore, the early correction of nutrient deficiencies may, in some cases, mean the difference between total crop failure and a highly productive plantation(Ballard 1984).

Foliar analysis has been the preferred method of evaluating tree nutrient status because it provides an integrated assessment of the many factors that influence nutrition. Data from foliar analysis can be interpreted using vector analysis. Vector analysis provides an opportunity to simultaneously compare plant growth, nutrient concentration and nutrient content on one graph (Haase and Rose 1995). This technique allows to detect dilution effects, nutrient imbalances and interactions. Vector analysis was applied to interpret loblolly pine response to applied N and P on a Beauregard silt loam in central Louisiana. The objective of this study was to determine the response of loblolly pine to combined N and P fertilizers in the presence of applied K on a Beauregard silt loam.

MATERIALS AND METHODS

Description of the Area

Three 12-m X 12-m visually homogeneous plots were selected for the study at the Kisatchie National Forest, Rapides Parish, Louisiana. The site receives an average annual rainfall of 1270 mm and has a mean annual temperature of 20 ^{0}C. The soil is a Beauregard silt loam. A loblolly pine plantation had previously occupied the site. Duplicate auger soil samples from O-l 5 cm and 15-30 cm depths were randomly obtained from the three plots and bulked for base line nutrient analysis (table 1). Samples were analyzed for pH (1:2 in deionized water), exchangeable bases by 1 M NH_4OAc (Thomas 1982), Al by 0.1 M $BaCl_2$-NH_4Cl (Barnhisel and Bertsch 1982), CEC by NH_4OAc at pH 7 (Soil Survey Laboratory Staff 1992), organic matter by acid-dichromate oxidation (Nelson and Sommers 1982), Bray II P (Bray and Kurtz 1945) and particle size by hydrometer method (Gee and Bauder 1986).

Design and Fertilizers

The study employed the "continuous variable design" that was previously tested by Shoulders and Tiarks (1982) for loblolly pine fertilization. The design was replicated three times. The advantages and disadvantages of the design for exploratory fertilizer trials were described by Fox (1973) and Shoulders and Tiarks (1982). Each replication (block) had a 10-m X 10-m area for 10 P and 10 N rates. Each l-m square represented a cell (fig. 1). A buffer space of 2 m was left on each side of the blocks. Buffer spaces received the same fertilizer treatment as the adjacent cells. Three loblolly pine seedlings were planted in a triangular arrangement with spacing of 0.6 m between seedlings within a cell. The closest spacing between seedlings in adjacent cells was 0.7 m. A half-sib source was seeded into containers in April 1995 and out planted in January 1996.

The rate of P and K was derived from P and K adsorption curve of the soil, while N was based on a previous study by Tiarks (1982) on the same soil. Ten levels of P and N were applied with the rates of P increased in one direction (vertical) and N in another (horizontal). The application rates of N in kg ha" were 0 (control), 10, 20, 30, 40, 80, 120, 160, 200, and 240. The rates of P in Kg ha^{-1} were 0 (control), 100, 200, 300, 400, 500, 600, 700, 800, and 900. The two border cells at the beginning and end of each row was fertilized at the same rate as the adjacent measurement cell (fig. 1). From the P adsorption curve, the application of 100 Kg ha^{-1} (45 ug P g^{-1} soil) was approximated to give 0.2 ug ml^{-1} equilibrium P solution. A comparable rate of 104 to 115 Kg ha^{-1} P was recommended by Tiarks (1982) to increase soil solution P to a level that gave 90 percent dry weight yield of greenhouse grown loblolly pine on the same soil series.

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Table l-Selected physical and chemical characteristics of the study soil. Given values are means and standard deviations (SD) for two depths from three plots

	Depth (cm)			
	O-l 5		15-30	
Property	Mean	SD	Mean	SD
Organic matter, percent	1.6	0.1	0.5	0.1
pH	4.9	.1	4.8	.1
P, mg kg^{-1}	1.6	.2	1.1	.2
K, $cmol(+)kg^{-1}$	.1	.0		.0
Ca, $cmol(+)kg^{-1}$	1.4	.3	1::	.1
Mg, $cmol(+)kg^{-1}$	.5		.5	.1
Al, $cmol(+)kg^{-1}$	.5	.5	1.5	.8
CEC, $cmol(+)kg^{-1}$	10.7	1.7	8.5	.8
Clay, percent	7.0	1.0	6.3	1.2
Silt, percent	59.3	2.1	61.0	3.0
Sand, percent	33.7	4.0	31.7	.6

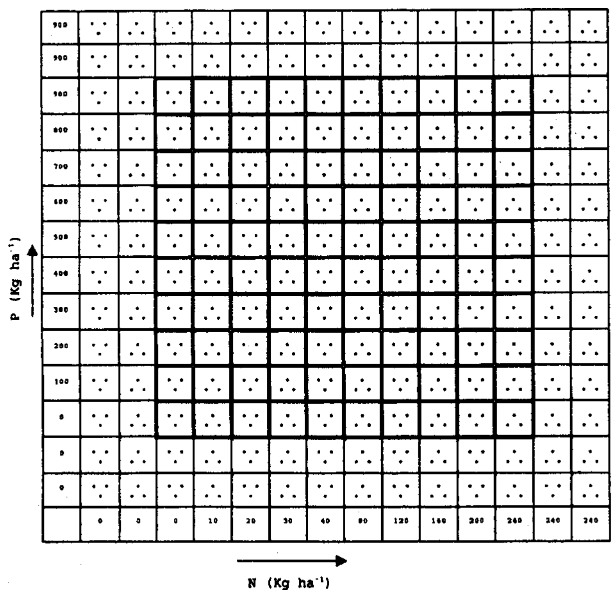


Figure l-Experimental plot layout.* Pine seedlings; distance between trees in a cell is 0.6 m and in adjacent cells is 0.7 m; 50 kg ha-' K for all cells. Nitrogen rates increase horizontally from 0 to 240 kg ha" and P rates increase vertically from 0 to 900 kg ha". This plot is replicated three times with a 2-m distance between each plot. Double line cells contain measurement trees.

About 0.22 mg L^{-1} of P in soil solution was required for the targeted maximum yield. Potassium was applied at constant rate of 50 kg ha-' to maintain nutrient balance in the plant. The rate was based on the soil's adsorption-desorption characteristics of K.

The plots were sprayed with Glyphosate (Roundup) and Sulfometuron (Oust) prior to planting and after fertilization to reduce weed competition. The appropriate amount of fertilizer was broadcast by hand four weeks after seedling planting. Nitrogen was applied as urea (45-O-O), phosphorus as triple superphosphate **(0-46-0),** and potassium as muriate of potash (O-O-SO).

Growth Measurements and Sampling

After one year of growth, one randomly selected tree from each cell was measured for height and ground level diameter, and harvested. Each harvested tree was partitioned into foliage, and wood (stem and branches) and dried for 48 h at 70 °C in a convection oven. The foliage and wood were separately weighed and ground with a Wiley mill to pass a 1 mm mesh in preparation for elemental analysis.

Tissue Analysis

Foliage and wood were analyzed for N by **a** CHN analyzer (EA 1108 Elemental Analyzer, Fison Instruments). Concentrations of P and K were determined by inductively coupled plasma-atomic emission spectroscopy (ICP) after samples were digested in HNO, and H_2O_2 using a temperature-controlled digestion block (Huang and **Schulte** 1985). The following modifications were made for this study (Personal communication. Paul Bell. 1997. Professor, Agronomy Dept., Louisiana Agricultural Experiment Station, Agricultural Center, LSU, 104 MB Sturgis, Baton Rouge, LA 70802): I) tissue samples that adhere to the inside wall of digestion tube, due to frothing caused by the reaction between acid and tissue sample were rinsed down with deionized H_2O; ii) contents were heated until 2 to 3 ml extractant remained; and iii) final solution was diluted to 25 ml instead of 50 ml. The modification allows for more complete digestion.

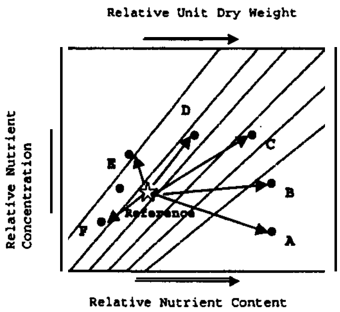
Data Analysis

Vector analysis was employed to graphically diagnose for presence of nutrient interaction and/or dilution as described by Hasse and Rose (1995). The data were normalized and the control (the cell without N and P treatment) was given a relative value of 1 .O. The interpretations, based on nutrient shifts (fig. **2),** were made according to Hasse and Rose (1995).

RESULTS AND DISCUSSION

Nitrogen

Vector diagrams are presented for N in foliage (fig. 3a) and N in wood (fig. 3b). Vectors to all points were not drawn because of the many data points (97 points, three data points missing). For N, most of the data points (about 80 percent in foliage and 90 percent in wood) exhibited an "A' and a "B shift". This is interpreted as N not being limiting. The few "F shifts" (antagonistic) were associated with N application without P, but these did not occur for all treatments of N without P. At higher N levels and P levels, a "C shift", a sign of N deficiency, was observed. The antagonistic effect of N-only application on N uptake was more prominent for wood than for foliage (fig. 3). This is possibly a result from more N demand in the foliage than in wood at the early stage of plant development, where the production of photosynthate is at its maximum (Gosz 1984).



Direction of shift	Dry weight	Response in Nutrient Conc.	Content	Interpretation	Possible Diagnosis
A	+	-	+	Dilution	Non-limiting
B	+	0	+	Sufficiency	Non-limiting
C	+	+	+	Deficiency	Limiting
D	0	+	+	Luxury consumption	Non-toxic
E	-	++	±	Excess	Toxic
F	-	-	-	Excess	Antagonistic

Figure 2—Interpretation of directional shifts in nutrient concentration, nutrient content, and dry weight (Haase and Rose, 1995).

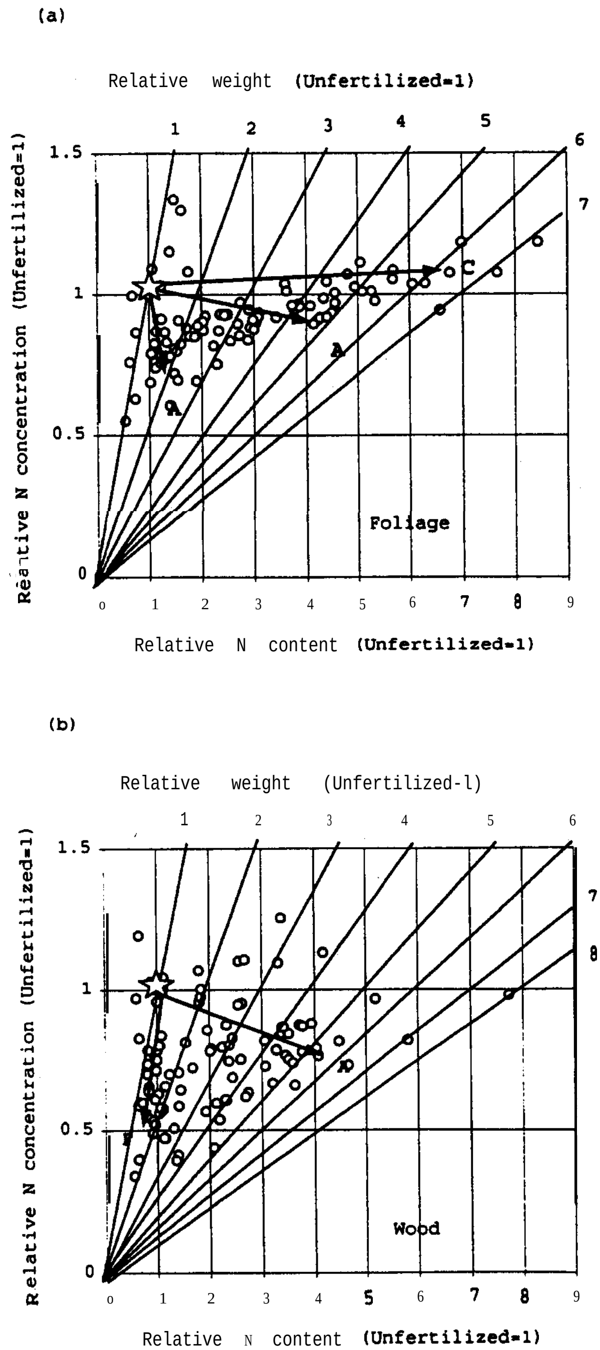


Figure 3-Relationship between N concentration, N content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. A = Dilution, C = Deficiency. (☆ = unfertilized trees).

The mean N concentration in foliage for unfertilized trees was 1.57 percent. At the highest N-only application, the mean was about 2.00 percent, and at the highest N and P combination, it was 1.88 percent. In general, an increase in N concentration was not noted until rates of N applied exceeded 160 Kg ha". For most cases, addition of a deficient nutrient induces a rapid increase in plant growth and its concentration (Timmer 1991). For semi-mature loblolly pine, the critical foliar N concentration is 1 .1 percent (Allen 1987). The N concentration in unfertilized trees exceeded the critical level, but it is recognized that for younger trees critical concentration may be higher than 1 .1 percent.

Phosphorus

Vector diagrams for foliage P (fig. 4a) and wood P (fig. 4b) show similar patterns for nutrient P shift. The combined N and P, and P-only treatments invariably resulted in a "C shii; showing that the trees would be P deficient if left unfertilized. A decrease in relative P concentration and relative P content ("F shift") was observed for trees fertilized with N alone, indicating the antagonistic effect of N on P uptake. Teng and Timmer (1994) demonstrated the antagonistic effect of N-only application in a study designed to test the nursery performance of white spruce [*Picea glauca* (Moench) Voss] with combined N and P fertilization. They attributed the antagonistic effect of N-only treatments to lower specific absorption rates of roots and suspected depletion of rhizospheric P. They also noted a synergistic effect of N and P uptake when these nutrients were applied together. Olykan and others (1995) also reported a significant decline in P concentration in the current needles of four-year-old *P. radiata* one year after fertilization with N alone.

Potassium

Figures 5a and 5b show major "A shift" (dilution). This dilution was caused mainly by combination of N and P. The "C shift" was associated with P-only application as well as P and N combination at low N levels. Nitrogen-only application had an antagonistic effect ("F shift") on K uptake both in oliage and wood. Relative K concentration was greater in foliage than in wood showing greater dilution in wood than oliage (table 2). Since K is mobile within the plant, it can be transported to the foliage (Tisdale and others 1985). In general, K appears to be sufficient for the ranges of N and P combination rates studied.

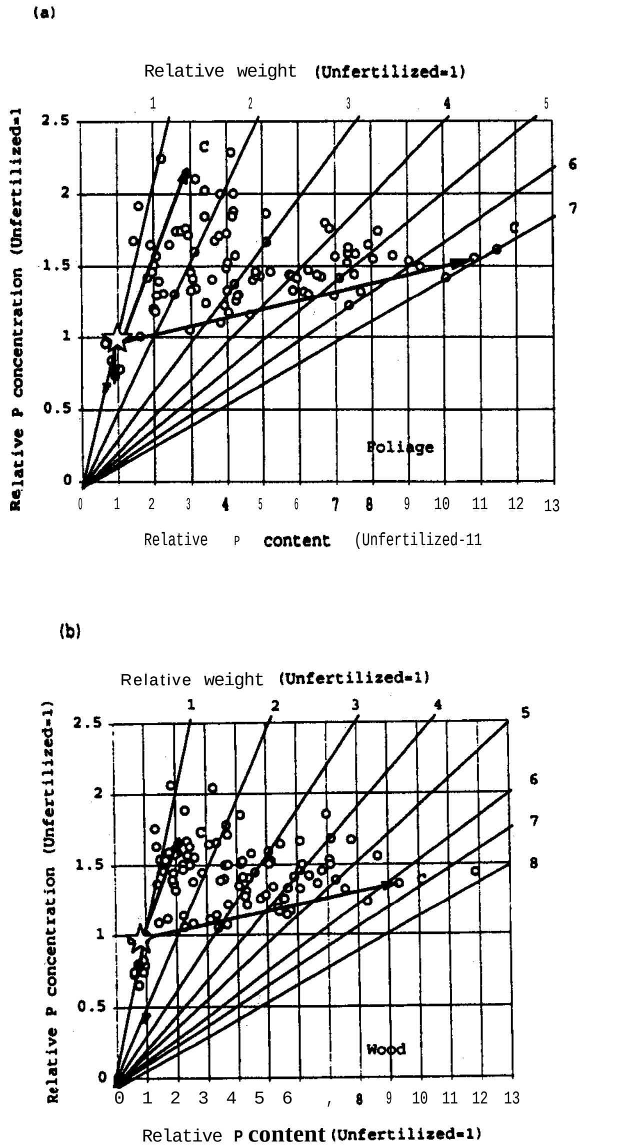


Figure 4—Relationship between P concentration, P content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. C = Deficiency, F = Antagonistic. (☆ = unfertilized trees).

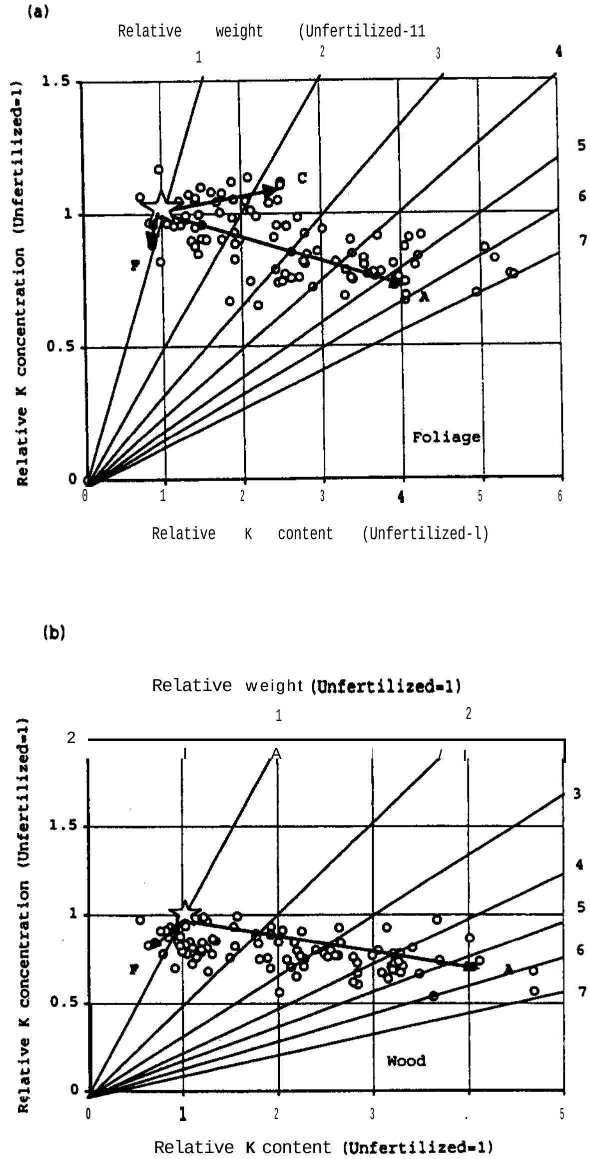


Figure 5—Relationship between K concentration, K content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. A = Dilution, C = Deficiency, F = Antagonistic. (☆ = unfertilized trees).

Calcium

The vector diagrams for foliage Ca and wood Ca are given in Figures 6a and 6b, respectively. The vectors were an "A shift", a "B shift" a "C shift" and an "F shift" for both foliage and wood. The observed "C shift" was not related to any particular N and P combination. Nitrogen-only fertilization had an antagonistic effect upon Ca uptake. In general, combined N and P application resulted in increased Ca utilization by the plant. Foliage Ca concentrations of unfertilized and fertilized trees was comparable (table 2) while a decrease was noted for wood part of fertilized trees. Thus, there was sufficient soil Ca (table 1) to sustain tree growth at the rates of N and P studied.

Table 2—Summary of nutrient concentration in foliage. of unfertilized and fertilized trees at 240 kg ha" N and 900 kg ha^{-1} P application, and critical nutrient level obtained from literature

	Unfertilized		Fertilized		Critical level
Nutrient	Foliage	Wood	Foliage	Wood	Foliage[a]
	Percent				
N	1.57	0.75	1.86	0.71	1.10
P	.09	.07	.16	.10	.09–0.10
K	.5	.40	.35	.22	.25–0.30
Ca	.26	.21	.25	.17	.12

[a] For semi-mature loblolly pine, Allen (1987).

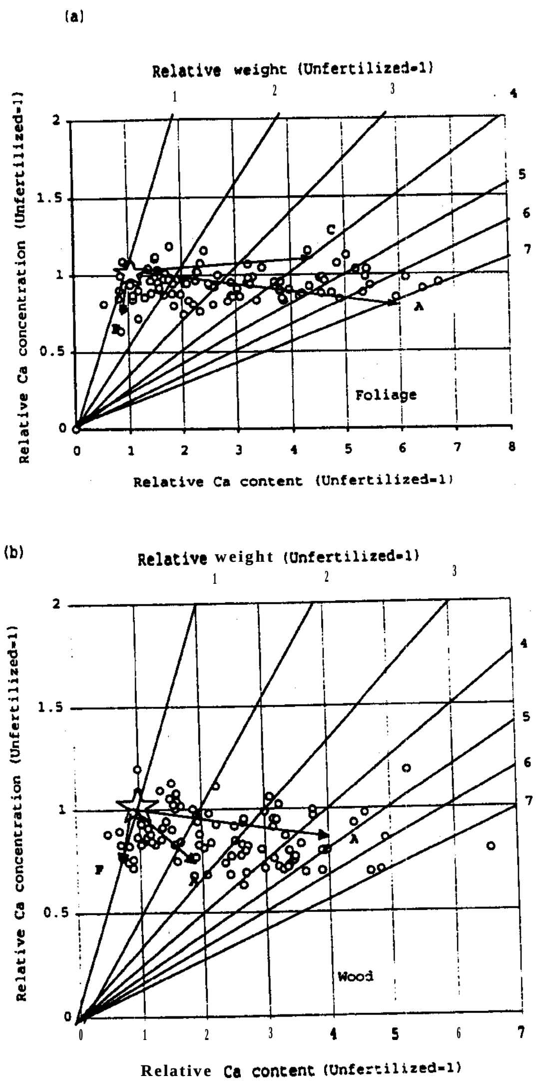


Figure 6-Relationship between Ca concentration, Ca content and dry weight of (a) foliage and (b) wood on a relative scale as affected by various rates of applied N and P. **A=Dilution, C=Deficiency, F=Antagonistic. (☆ =** unfertilized trees).

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