

NUTRITIONAL STATUS OF *Eucalyptus grandis* CLONES EVALUATED BY CRITICAL LEVEL AND DRIS METHODS¹

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ABSTRACT - Nutritional status of eight 1.0 and 4.7 years old clones of *Eucalyptus grandis*, cultivated in a medium textured Ustults - US - and a Quartzipsamments - PS - soils, in Lençóis Paulista, São Paulo, were evaluated by the Diagnosis and Recommendation Integrated System (DRIS) and Critical Level (CL) methods. Based on multivariate discriminant analysis, the DRIS indices described the nutritional status of trees better in relation to tree age and soil type than in relation to nutrient composition. Spearman's correlation coefficients showed statistically significant relationships between volumetric tree growth and nutrients when applying DRIS indices or foliar nutrient concentrations. However, the DRIS indices indicated a lower number of trees with nutritional deficiencies, in relation to the CL method. According to the CL method, P, S, and Ca were deficient in the majority of the soils and tree age categories. By the DRIS method, Ca was the only deficient nutrient in PS soils, and appeared to be particularly limited in one-year-old trees. In conclusion, the DRIS method was more efficient than the CL method in evaluating the nutritional status of eucalyptus trees.

Key words: Multivariate analysis, nutrient composition, calcium, eucalyptus.

AVALIAÇÃO NUTRICIONAL DE CLONES DE *Eucalyptus grandis*, PELOS MÉTODOS DO NÍVEL CRÍTICO E DO DRIS, EM ÁRVORES DE 1 E 5 ANOS DE IDADE

RESUMO - Avaliou-se o estado nutricional de oito clones de *Eucalyptus grandis*, com idade de 1,0 e 4,7 anos, cultivados em dois solos (Neossolo Quartzarênico - PS e Argissolo Vermelho Amarelo - US), pelos métodos do nível crítico e do DRIS. Os índices DRIS apresentaram maior coerência para o padrão nutricional determinado pelo local de crescimento e pela idade das árvores, em comparação à concentração dos nutrientes, com base na análise multivariada discriminante. A maioria dos nutrientes, tanto em relação à concentração como ao índice DRIS, apresentou correlações significativas com o crescimento volumétrico da árvore, pela análise de correlação de Spearman. Contudo, o DRIS foi mais conservador que o método do NC na indicação de deficiências nutricionais: P, S e Ca foram apontados como deficientes pelo método do NC, em todos os solos e em todas as idades. Pelo método do DRIS, somente a deficiência de Ca foi apontada como sendo mais severa no solo PS e, principalmente, nas árvores de 1 ano de idade. Conclui-se que o método do DRIS foi superior ao método do NC para avaliação nutricional de árvores.

Palavras-chave: Análise multivariada, concentração de nutrientes, cálcio e eucalipto.

1. INTRODUCTION

In Brazil, eucalyptus has been cultivated generally on savanna soils of low natural fertility (Barros & Novais, 1996; Reis & Barros, 1990) with limited capacity to

support production caused by significant declines in mineral reserves by continuous harvest cycles (Leal et al., 1988). Thus, the nutritional balance in eucalyptus plantations is negative, because nutrient take uptake is higher than the nutrient inputs.

¹ Recebido para publicação em 13.11.2002 e aceito para publicação em 17.2.2004.

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Fertilizer application on soil under eucalyptus plantations is undoubtedly expensive because of the extensive plantation areas. Therefore, it is necessary to develop methods of diagnosis and fertilizer recommendations which can lead to improved fertilizer recommendation and forestry productivity. The nutrient diagnostic method should identify cases in which a nutrient limits yield. Situations should also be identified, in which the nutrient does not limit yield, in order to optimize biological and economic productivity.

In order to optimize biological productivity, nutritional evaluation based on foliar analysis using the DRIS or CL methods (Schutz & Villiers, 1987; Arboleda et al., 1988; Hockman et al., 1989; Rathfon & Burger, 1991; Malavolta et al., 1993) has been applied in trees. However, the DRIS method was more accurate. Foliar analysis was used because the leaves are the plant compartment where most metabolic activities take place, and their physiological and nutritional status may influence plant growth. Thus, leaves are the main plant tissue used for nutritional diagnosis (Malavolta et al., 1999). In Brazil, Wadt & Novais (1999) evaluated the N eucalyptus nutrition by DRIS using the ratios between nutrient allocated to each tree component (compartmentalized analysis): leaves, branches, stem bark and stemwood, or integrating the ratios for all the tree components simultaneously (integrated analysis). The DRIS indices by compartmentalized analysis showed a poorer relation with forest productivity than the DRIS indices by integrated analysis. The integrated analysis to evaluate the nutritional status of mature eucalyptus plantations is expensive.

To use the DRIS indices by compartmentalized analysis the Nutrient Application Potential Response (NAPR) criterion was adopted. NAPR is one criterion of DRIS indices interpretation and classification (Wadt, 1996; Martinez et al., 1999; Wadt et al., 1999) based on the probability of highest fertilizer response to the nutrient DRIS indices were lower, negative and had higher nutritional imbalance than other nutrient analyzed (Wadt, 1996).

Therefore, the objective of this paper was to evaluate the nutritional status of *Eucalyptus grandis* W. Hill ex Maiden trees of 1.0 and 4.7 years of age to compare two diagnosis methods (CL and DRIS methods by compartmentalized analysis), using NAPR criterion and independent DRIS norms and CL values.

2. MATERIALS AND METHODS

The DRIS norms were obtained through quantification of N, P, K, Ca, Mg, S, B, Zn, Mn, Fe and Cu nutrient composition of 1,986 sites of commercial 4.5 to 10 year old stands cultivated with *Eucalyptus grandis* x *E. urophylla* clones in the states of Espírito Santo and Bahia, Brazil (Wadt & Novais, 1999). Foliar nutrients in trees from 80 clones and 9 management units were analyzed, irrespective of phenologic period, physiological age of the leaves, position of leaves in the tree or canopy, or growing season. The DRIS norms consisted of the mean, variance, and the maximum and minimum values for bivariate relations of these foliar nutrient concentrations for low, medium and high productivity subpopulations (Wadt, 1996).

Field experimental data on foliar nutrient concentration composition and eucalyptus productivity of 1.0 and 4.7 year old trees were used to evaluate the performance of the following nutritional diagnostic methods: Critical Level (CL) and DRIS (Integrated System for Diagnosis and Recommendation). Field experiment data consisted of the mean foliar nutrient concentration of 48 trees (16 trees x 3 replications) of eight clones of *Eucalyptus grandis*, cultivated in Ultults (US) and Quartzipsamments (PS) soil, in Lençóis Paulista, São Paulo, Brazil. These data were published by Vettorazzo (1989), and represent the mean foliar nutrient concentrations for N, P, K, Ca, Mg and S nutrients (in g/kg), the mean foliar nutrient concentrations for B, Cu, Fe, Mn and Zn nutrients (in mg/kg), and tree productivity (in m³/ha).

Critical values for the nutritional status of eucalyptus trees using the Critical Levels method were obtained from Schönau (1983), for N (20 g/kg), P (1.6 g/kg), K (7.0 g/kg), Ca (10.0 g/kg), Mg (3.0 g/kg) and S (1.8 g/kg). Trees were deficient if nutrient concentrations were lower than the critical values indicated and optimum if nutrient concentrations were the same or higher than the values indicated.

For DRIS method, the DRIS indices were calculated using the Jones formula (Jones, 1981), and the Dry Matter index (Jones, 1981) was also calculated. DRIS indices were grouped according to the Nutrient Application Potential Response (NAPR) criterion (Wadt, 1996; Martinez et al., 1999; Wadt et al., 1999). For NAPR, the DRIS indices were classified into five categories (Table 1).

Table 1 - Interpretation of DRIS indices by the nutrient application potential response method (WADT, 1996). (I_{Nut} = DRIS index for the nutrient and, $mNBI$ = mean nutritional balance index)**Quadro 1** - Interpretação dos índices DRIS pelo método do potencial de resposta à adubação (WADT, 1996). (I_{Nut} = índice DRIS para um dado nutriente; e $mNBI$ = índice de balanço nutricional médio)

Nutritional status	Nutrient application potential response ^{1/}	Condition
Deficient	Positive, high probability	$I_{Nut} < 0$ and $ I_{Nut} > mNBI$ and I_{Nut} DRIS index is lower
Probable deficiency	Positive, low probability	$I_{Nut} < 0$ and $ I_{Nut} > mNBI$
Balanced	Null	$ I_{Nut} \leq mNBI$ and
Probable excess	Negative, low probability	$I_{Nut} > 0$ and $ I_{Nut} > mNBI$
Excess	Negative, high probability	$I_{Nut} > 0$ and $ I_{Nut} > mNBI$ and I_{Nut} DRIS index is higher

^{1/} A positive response implies that nutrient inputs would increase tree growth rates and a negative response implies that nutrient inputs would decrease tree growth rates.

In the discriminant statistical analysis (Manly, 1994) using SPSS software (SPSS, 1995), trees were grouped into soil type (PS or US) and tree age (1.0 or 4.7 years). These groupings into homogeneous tree groups were termed actual grouping. Statistical agreement between actual grouping and predicted grouping were tested by discriminations using Mahalanobis distances defined from nutrient composition or DRIS indices. The percentage of correct allocations as an indication of how well groups can be separated using the nutrient composition or DRIS indices variables was calculated.

Finally, for 1.0 and 4.7 year old trees, the values for nutrient composition, DRIS indices, and tree productivity were ordered by ranking the higher values. Spearman's correlation coefficients were employed to determine the respective significance for nutrient composition or DRIS indices in relation to tree productivity.

3. RESULTS AND DISCUSSION

The DRIS method classified satisfactorily the actual grouping of trees cultivated in PS soil, failing only in two tree groupings of 1.0 year old trees cultivated in US soil (Table 2). The correlation between actual grouping and predicted grouping was 93.75% in relation to all cases.

Groupings based on nutrient composition correctly classified 1.0 year old groupings in US soil and 4.7 year

old groupings in PS soil. In this method, four clones were incorrectly grouped: three with 4.7 year old trees in US, and one with 1.0 year old trees in PS soil (Table 2). The correlation between actual grouping and predicted grouping was 87.50% in relation to all cases. Therefore, the DRIS indices were superior to the nutrient composition in classifying tree nutritional status based on tree age and soil type.

Compared to the CL method, the DRIS method was more conservative in identifying nutritional deficiencies. When employed CL, 100% of clones were considered S and Ca deficient; 97% were P deficient; 71% were Mg deficient and 34% were N or K deficient (Table 3). By DRIS methods, 50% of the clones were considered Ca-deficient and 3% were considered Mg-deficient with a high probability of response to lime application. With lower deficiency probability, 44, 19 and 12.5% of the cases were Mg, Ca and P deficient (Table 3).

The suggestion of a Ca deficiency by the DRIS method is probably correct in PS soil. However, in relation to the two methods, DRIS suggested 50% lower Ca deficiency than the CL method. If the Ca deficiency is false in US soil, the accuracy of DRIS methods should be higher.

In 1.0-year-old trees, the N, P, Ca, Mg, Fe, Mn and Zn concentrations were correlated with tree productivity ($p = 0.05$). However, no correlations were observed for N, P and Zn DRIS indices and tree productivity. Only

Table 2 - Summary of foliar nutrition classification in relation to actual groups (based on soil type and tree age) versus the predicted group membership by the canonical discriminant function derived by DRIS indices or nutrient composition. The percent of "grouped" cases correctly classified was 87.5% for nutrient composition and 93.7% for DRIS indices

Quadro 2 - Resumo da classificação da nutrição foliar em relação a grupos atuais, com base no tipo de solo e na idade da árvore, pelo agrupamento predito pelas funções canônicas derivadas dos índices DRIS ou da composição nutricional. A porcentagem de casos agrupados corretamente foi de 87,5% para as variáveis derivadas da composição nutricional e de 93,7% para aquelas derivadas dos índices DRIS

Actual cases				Predict cases (number allocated to group)							
	Soil	OT ^{1/}	SC ^{2/}	CL method				DRIS method			
				Ustults (US)		Quartzipsamments (PS)		Ustults (US)		Quartzipsamments (PS)	
				4.7 ^{2/}	1.0	4.7	1.0	4.7	1.0	4.7	1.0
Nº cases	US	4.7	8	5	2	1	0	8	0	0	0
% ^{4/}				62.5	25.0	12.5	0.0	100.0	0.0	0.0	0.0
Nº cases	US	1.0	8	0	8	0	0	0	6	0	2
%				0.0	100.0	0.0	0.0	0.0	75.0	0.0	25.0
Nº cases	PS	4.7	8	0	0	8	0	0	0	8	0
%				0.0	0.0	100.0	0.0	0.0	0.0	100.0	0.0
Nº cases	PS	1.0	8	0	1	0	7	0	0	0	8
%				0.0	12.5	0.0	87.5	0.0	0.0	0.0	100.0

^{1/} tree age; ^{2/} sum of cases; ^{3/} tree age; and ^{4/} percent of cases.

the K, Ca, Mg, Fe and Mn DRIS indices were correlated to the same significance level (Table 4). The lack of agreement between the two variables (DRIS indices and nutrient composition) was due to concentration and dilution effects (Jarrel & Beverly, 1981), and shown by the high correlations observed between DRIS indices and dry matter indices in these tree ages (Table 4).

In 4.7-year-old trees, the P, K, Ca, Mg, B, Fe, Mn and Zn concentrations and DRIS indices were correlated with tree productivity ($p = 0.05$). Agreement between the variables was also good, probably because of the lowest nutrient concentration and dilution effects. In 4.7-year-old trees, the correlation between DRIS indices and trees productivity was also lower (Table 4).

The bivariate correlation technique did not permit identification of cause and effect between nutrient composition or DRIS indices and tree productivity. However, regardless of soil type and tree age, the correlations between Ca nutrient and tree productivity were the highest or second highest Spearman correlation coefficient.

Eighty one percent of the cases for the highest probability of response potential of Ca application by DRIS methods were restricted to trees cultivated in PS soil, at 1.0 year old (100% of these clones were considered Ca deficient by DRIS) and the Ca deficiency was lower in 4.7-years-old trees cultivated in the PS soil.

The Ca deficiency was higher in sandy soils. The hypothesis is that the relative biomass accumulation rate was higher than the relative Ca accumulation rate (Ingestad & Ågreen, 1995) in these soils during the period of highest relative biomass growth in 1.0 year old trees. The lack of Ca deficiency in 4.7 year old trees was attributed to lowest tree growth rate, due the highest tree competition and highest nutrient cycling rate, increasing the Ca liberation for radical absorption.

Table 3 - Total number of Eucalyptus clone cases with nutritional deficiencies (evaluated by the Critical Levels and Fertilization Response Potential methods), for the N, P, S, K, Ca and Mg nutrients, of 1.0- and 4.7-year old clones cultivated in PS and US soils

Quadro 3 - Número total de casos de clones de eucalipto com deficiência nutricional (avaliado pelos métodos do nível crítico e do potencial de resposta à adubação), para os nutrientes N, P, S, K, Ca e Mg, de clones de 1,0 e 4,7 anos cultivados em Neossolo Quartzarênico e Argissolo Vermelho-Amarelo

Nutrient	Critical level	DRIS - Fertilization Response Potential	
		Positive potential with:	
	Deficient	high probability	low probability
N	11	0	0
P	31	0	4
S	32	0	0
K	14	0	0
Ca	32	16	6
Mg	23	1	14

Table 4 – Meteorological data in Lençóis Paulista, from 1984 to 1989**Quadro 4** – Dados meteorológicos médios de Lençóis Paulista, no período de 1984 a 1989

Meteorological parameters	J	F	M	A	M	J	J	A	S	O	N	D
Mean maximum temperature (°C)	30.0	29.6	29.9	28.2	24.2	23.6	24.7	26.2	27.2	30.0	30.0	30.1
Mean minimum temperature (°C)	16.3	16.3	15.3	14.1	10.0	6.1	6.1	6.9	9.7	11.9	13.6	14.9
Precipitation (mm)	226	232	153	74	101	61	18	53	55	79	121	145
Rain day's number	31	28	31	30	31	31	29	30	29	26	28	31

Source: Appendice 1 for Vettorazzo (1989).

In the Lençóis Paulista region, water deficiency is low, particularly when considering the same retention capacity of water by US and PS soils (Table 4). However, the soil water retention capacity and retention energy was probably lower in PS soils when compared to US soils, because coarse materials are higher in PS soil and fine materials are higher in US soil. This suggests that water deficiency probably differs between microenvironments.

However, the higher Ca deficiency in PS soils, identified by DRIS methods, may be explained by mass flow interruption. It is possible that in PS soil, root Ca absorption was reduced during periods when tree transpiration was relatively high because the turgor potential was sufficient for meristematic growth. Therefore, the tree was able to maintain relatively high growth rates under low water transpiration and Ca demand. This rationale would explain the reason for low Ca depletion in PS soil when compared to US soils (Table 5).

The high correlation coefficients between other nutrients concentrations and tree productivity suggest that other nutritional factors are able to control tree growth rate (Table 6). In this study, Ca deficiency was attributed to a lack of parallel rates between relative Ca

Table 5 – Calcium concentration in soils PS and US, in mmol/dm³**Tabela 5** – Concentração de cálcio nos solos Neossolo Quartzarênico e Argissolo Vermelho-Amarelo, em mmol/dm³

Soil	Prof. (cm)	Initiation of Experiment (Aug-84)	Prof. (cm)	After 4,5 years (Feb-89)
Ustults	0-20	20.0	0-15	3.5
			15-40	0.5
Quartzipsamments	0-20	1.0	0-15	1.3
			15-40	1.6

Source: Table 1 and 3 for Vettorazzo (1989).

Table 6 – Spearman's coefficient and significance (Sig) for correlation between tree growth estimate and nutrient composition (NC) or DRIS indices (DI), for the 1.0 and 4.7-year-old clones cultivated in PS and US soils**Tabela 6** – Coeficiente de Spearman e significância (Sig) para correlação entre estimativa do crescimento da árvore e composição mineral (NC) ou índices DRIS (DI), para clones de 1,0 e 4,7 anos de idade, cultivados em Neossolo Quartzarênico e Argissolo Vermelho-Amarelo

Nutrient	1.0-years-old trees				4.7-years-old trees			
	NC	Sig ^{1/}	DI	Sig	NC	Sig	DI	Sig
N	0.86	0.000	-0.01	0.983	0.34	0.197	0.23	0.393
P	0.64	0.008	0.37	0.154	-0.53	0.036	-0.70	0.003
K	0.19	0.477	-0.65	0.006	0.77	0.000	0.65	0.007
Ca	0.82	0.000	0.85	0.000	0.83	0.000	0.81	0.000
Mg	0.77	0.000	0.68	0.004	0.88	0.000	0.86	0.000
S	0.37	0.161	-0.47	0.064	-0.18	0.495	-0.24	0.374
B	0.28	0.297	-0.28	0.297	-0.61	0.012	-0.77	0.000
Cu	0.33	0.211	-0.19	0.471	-0.33	0.207	-0.37	0.161
Fe	-0.55	0.027	-0.77	0.000	0.58	0.018	0.49	0.052
Mn	-0.71	0.002	-0.81	0.000	0.68	0.004	0.53	0.034
Zn	0.74	0.001	0.06	0.812	-0.81	0.000	-0.84	0.000
dry matter			-0.78	0.000			-0.55	0.027

^{1/} in fractionary number.

accumulation and relative biomass growth. The tree response for Ca application is improbable because limiting absorption of Ca in the PS soil was dependent upon mass flux in periods of water deficit.

4. CONCLUSION

DRIS methods using NAPR criterion were superior to CL methods in diagnosing nutrient deficiencies. High Ca deficiency was due to the limited Ca absorption in PS soil during periods of water deficit in trees with high relative biomass growth.

5. ACKNOWLEDGEMENT

I wish to thank Karen A. Kainer - University of Florida for revising the original paper.

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