VOLUME ESTIMATES OF *ARAUCARIA ANGUSTIFOLIA* (BERT.) O. KTZE. USING AERIAL PHOTOGRAPHS.

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1. INTRODUCTION

Since 1974 the "Instituto Florestal", organism of Secretary of Agriculture and Supply of São Paulo State develops studies in natural resources using aerial photographs (SERRA Fº et alii, 1974 e 1975; AOKI et alii, 1976 and GALLOZZI et alii, 1979).

After 1979, with the technical-scientific cooperation provided by JICA (Japan International Cooperation Agency), research about volumetric estimates of man-made forest were initiated by CHYO & AOKI (1982).

This study was carried out at Melhoramentos Company, located in Caieiras, São Paulo State and the feasibility of volume estimates of *Araucaria angustifolia* (Berth.) O. Ktze. was verified using panchromatic aerial photographs at the scale 1:8,000. The height, number of trees and crown diameter data obtained from aerial photographs and applied in different regression models, showed that the most adequate equation to estimate to volume is: $V = 27.6 + 0.0000320\ n^2 + 1.37\ \overline{CD}^3 + 0.000240\ n^2\ \overline{CD}$, where V= volume, n = number of trees on aerial photographs and $\overline{CD}$ = crow diameter.

2. MATERIAL AND METHODS

2.1 Study area

It was chosen the "Companhia Melhoramentos de São Paulo - Indústrias de Papel-Caieiras" (CMSP), its localization and availability of aerial photogrammetric material.
According to GUIDONI & KONECSNI (1982), the "CMSP" is located into Great São Paulo in the km 34 at old Campinas road, between the geographical coordinates: longitude W.Gr. 46º44', latitude W. Gr. 23º24' (FIG.1). The ground is ondulated and presents few level areas, being the mean altitude 780 meters. The area belongs to a watershed plenty of strems and rivers. The seasons of year are well characterized with, hot summer and cold winter.

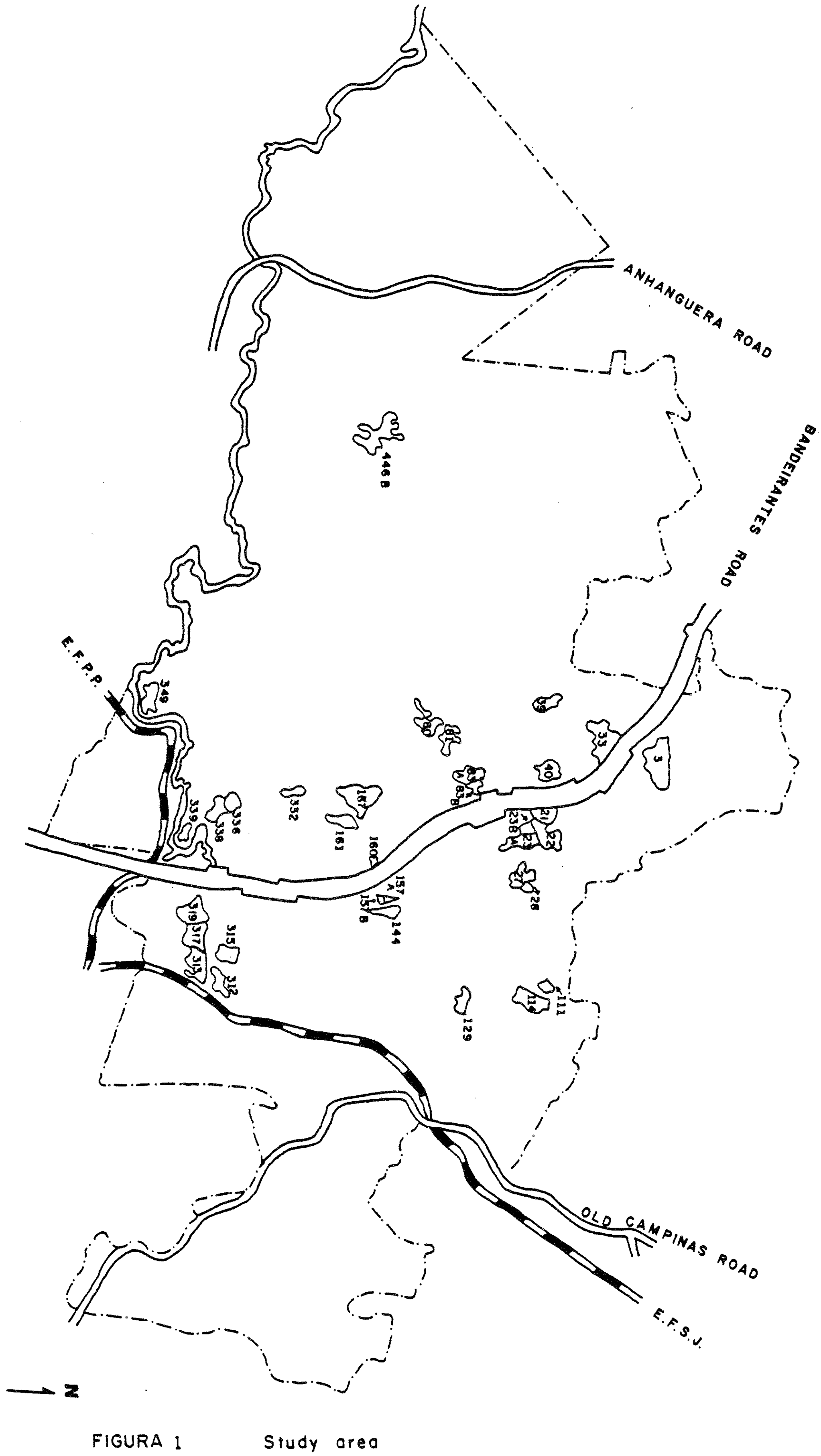

FIGURA 1 Study area Esc. 1:50.000

2.2 Photographic and Cartographic material

Panchromatic photograps at scale 1:8,000 from 1978, and topographic maps at scale 1:10,000 were utilized.

2.3 Equipment an others materials

Mirror stereoscope, parallax bar, couting tree transparency, dot or circle gauge to measure crown diameter and digitizer.

2.4 Methodology

The height, number of trees and crown diameter data obtained from 34 foreststands by measurements on aerial photographs were adjusted by multiple regression analysis. The tree height was obtained by measurement of the parallax difference on stereoscopic pairs of aerial photographs, which formula is:

$$h = \frac{H + dP}{P + dP}, \quad \text{where}$$

h = tree height; H = altitude of aircraft above ground datum;

p = absolute stereoscopic parallax at base of tree being measured; and

dP= differential parallax.

The crown diameter is measured with the dot or circle gauge, that consists of a row of dots or circles in different sizes (FIG. 2). The gauge is shifted close to the tree crow until that circle is adjacent to the crown, which corresponds closest to the area of the crown. According to LOETSCH & HALLER (1973), the results are almost as accurate as those of micrometer wedge.

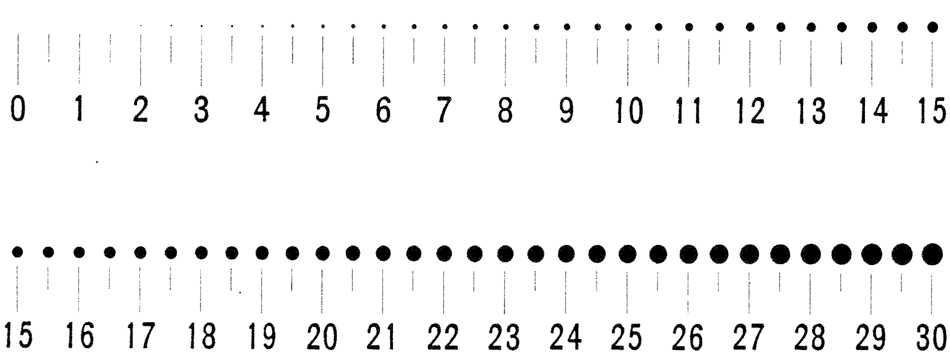

FIGURE 2 - Circle gauge or dot to crown diameter measurement

The number of trees is determined by using a transparency (FIG. 3), containing different sample units (0.04, 0.05 and 0.10 ha) and scales varying from 1:7,000 to 1:10,000, whose formula is:

$$N = \frac{N'}{A},$$

where N = number of trees/ha; N' = number of trees counted in the sample unit, and A = size of sample unit.

3. RESULTS AND DISCUSSION

The table 1 presents the number of trees and the crown diameter and volume estimates data obtained in terms of average values; the tree height data were not considered because there was a great deal of variance among them.

3.1 Number of trees

The equation that express the relation between the number of trees counted on aerial photographs and on the ground, with standard deviation of 17.7% is:

$$N = -144.3 + 1.82\, n \qquad R = 0.946$$

or

$$N = 56.6 + 0.730\, n + 0.00132\, n^2 \qquad R = 0.953$$

where N = estimated number of trees/ha; n = mean no of trees on aerial photographs; and R = multiple correlation coefficient.

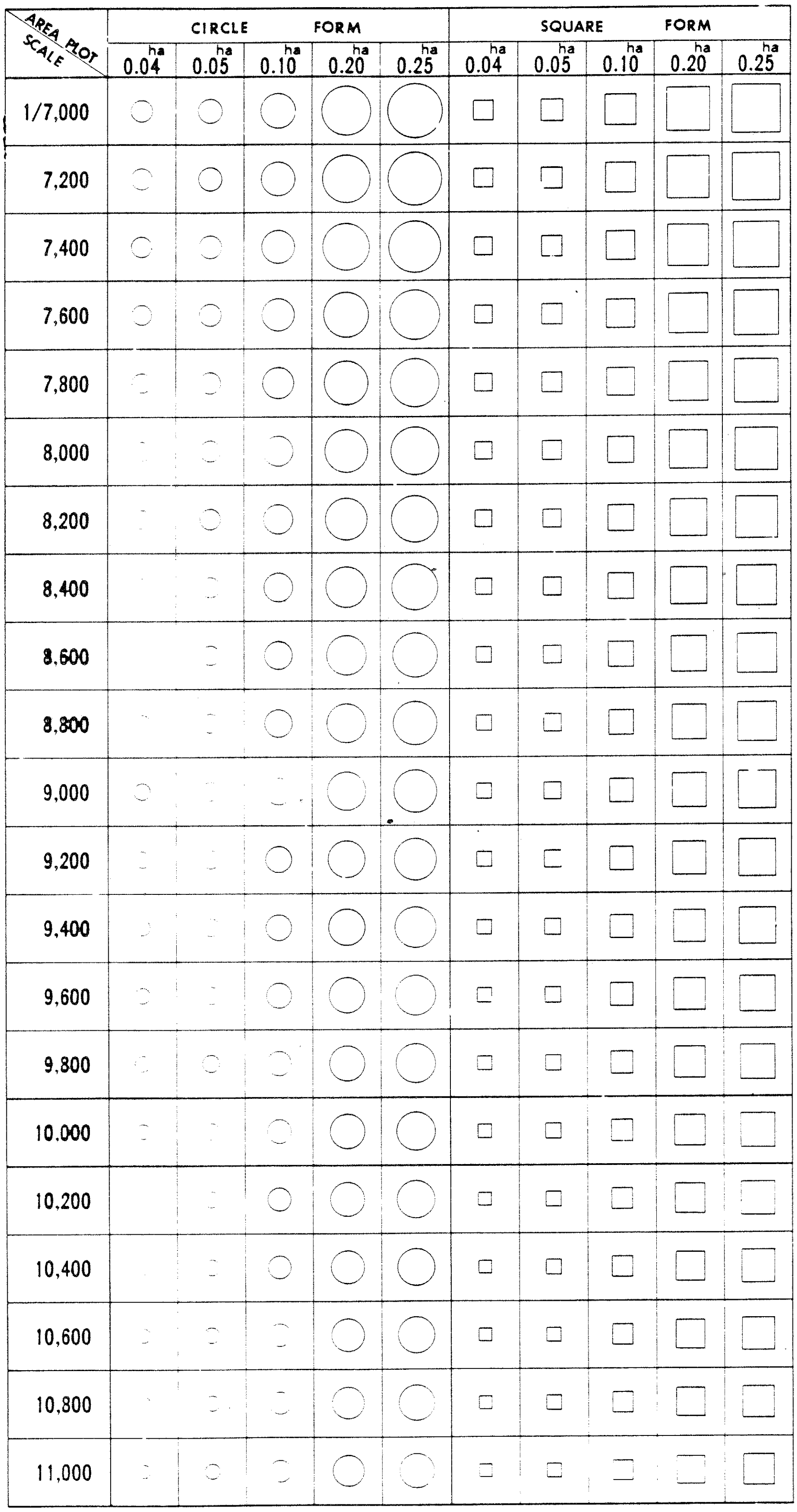

FIGURA 3 Transparency for determination of the number of trees

TABLE 1 - Number of trees, crown diameter, and volume estimates data

No.	Plot No	No of trees: Ground observation	No of trees: Photo observation	crow diameter (m): Photo observation	volume (m^3/ha): Ground observation	volume (m^3/ha): Photo observation
1	3	520	408	3.0	199.2	189.9
2	21	740	437	3.3	266.5	234.3
3	22	710	508	3.1	237.9	268.8
4	23 A	620	418	3.7	209.9	257.9
5	23 B	780	482	3.6	295.4	299.8
6	27	280	243	5.3	281.6	309.1
7	28	280	263	4.4	211.1	219.8
8	33	635	355	3.4	246.1	188.4
9	39	420	359	3.6	209.6	207.1
10	40	950	622	3.4	438.2	409.6
11	80	790	497	3.2	295.0	270.2
12	81	500	451	3.3	194.5	244.5
13	83 A	715	422	3.6	304.6	251.2
14	83 B	607	370	4.0	285.7	251.3
15	111	1320	733	1.9	302.0	299.3
16	114	510	348	3.7	218.4	208.6
17	129	350	301	4.3	197.0	233.2
18	144	346	265	5.3	339.0	323.6
19	157 A	275	225	5.4	287.6	311.1
20	157 B	325	230	5.3	313.1	301.0
21	160	308	198	5.3	300.9	283.2
22	161	267	211	5.4	330.9	303.0
23	167	240	240	5.3	312.3	307.2
24	312	308	212	5.7	382.4	344.9
25	313	580	380	3.7	178.5	230.0
26	315	282	202	5.5	264.9	311.3
27	319	520	372	3.9	218.5	243.0
28	332	280	221	5.1	240.1	271.1
29	336	510	410	3.5	188.4	233.0
30	338	385	358	4.0	298.4	242.6
31	339	340	313	4.1	258.9	221.8
32	349	630	524	3.0	289.5	271.1
33	361	1015	561	2.9	292.7	290.2
34	446	840	520	3.2	231.1	288.9

The graphic representation of this equation is shown in FIGURE 4.

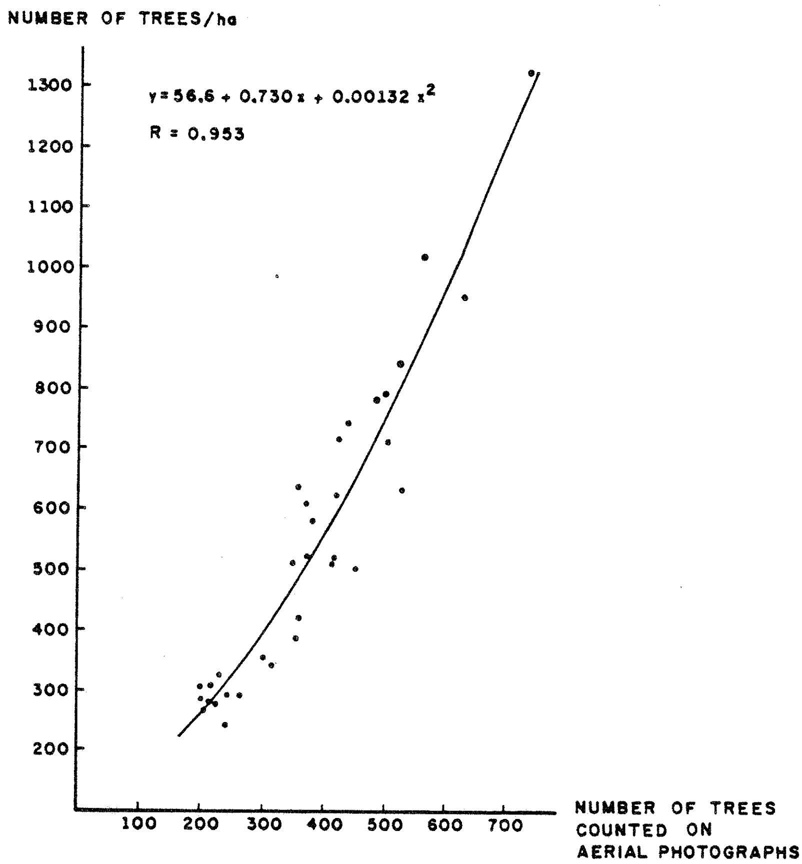

FIGURE 4 - Relation between no. of trees on the ground and in aerial photographs.

It was verified that the number of trees on aerial photographs represents 60% to 80% when the number of trees on the ground do not pass 1,000 (TABLE 2). Usually the number of counted trees is too small and according to SEELY, apud LOETSCH & HALLER (1973), tree counts on aerial photographs rarely give more than 50 per cent of the actual number of trees.

TABLE 2 - Percentage of counting trees

NUMBER OF TREES		COUNTING PERCENTAGE
PHOTO OBSERVATION	GROUND OBSERVATION	
200	255	78
300	394	76
400	560	71
500	752	66
600	970	62

3.2 Crown diameter

The standard deviation of the crown diameter measured was of 9.8%, and relations of crown diameter to diameter breast height (DBH) and to height were expressed by the following equations and are represented in FIGURES 5 and 6:

$$D = 4.14 + 5.04\ \overline{CD} \quad R = 0.938$$

$$D = 17.8 - 1.93\ \overline{CD} + 0.841\ \overline{CD}^2 \quad R = 0.951$$

$$D = 22.9 - 6.50\ \overline{CD} + 2.12\ \overline{CD}^2 - 0.113\ \overline{CD}^3 \quad R = 0.951$$

$$H = 11.8 + 2.03\ \overline{CD} \quad R = 0.857$$

where, D = estimated DBH; H = estimated height; $\overline{CD}$ = crown diameter measured on aerial photographs; and R = multiple correlation coefficient.

The adaptation of polinomial equation is the best to DBH estimate and, the linear equation to height (H) estimate.

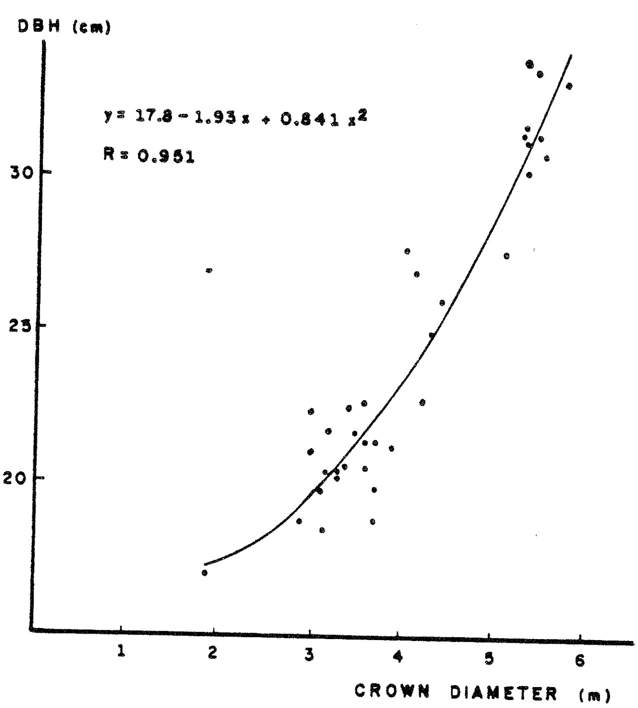

FIGURE 5 - Relation between DBH and $\overline{CD}$.

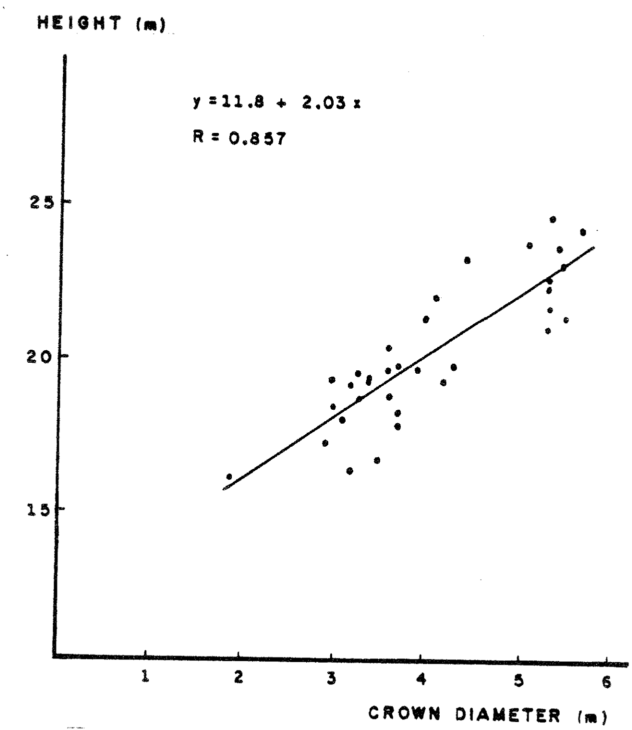

FIGURE 6 - Relation between H and $\overline{CD}$.

The individual volume was calculeted on the ground dividing total volume by number of trees and the individual volume and crown diameter relation can be expressed by the following equations, whose graphic representation is showed in the FIGURE 7.

$V_i = -0.617 + 0.305\ \overline{CD} \qquad R = 0.925$

$V_i = 0.474 - 0.252\ \overline{CD} + 0.0672\ \overline{CD}^2 \qquad R = 0.947$

$V_i = 0.195 - 0.00787\ \overline{CD} + 0.00587\ \overline{CD}^3 \quad R = 0.946$

$V_i = 0.178 - 0.000683\ \overline{CD}^2 + 0.00583\ \overline{CD}^3 \quad R = 0.946$

$V_i = 0.667 - 0.423\ \overline{CD} + 0.115\ \overline{CD}^2 - 0.00425\ \overline{CD}^3 \quad R = 0.947$

where V_i estimated individual volume; $\overline{CD}$ = crown diameter, and R = multiple correlation coefficient.

The second equation adaptation is the most adequate to individual volumes estimates.

In this study, the height was substituted by crown diameter, because is measurement presented difficulties due to irregular topographic conditions. Indeed, it was possible to estimate tree average height throughout crown diameter with close multiple correlation coefficient (R = 0.899), as well as individual volume (R = 0.947).

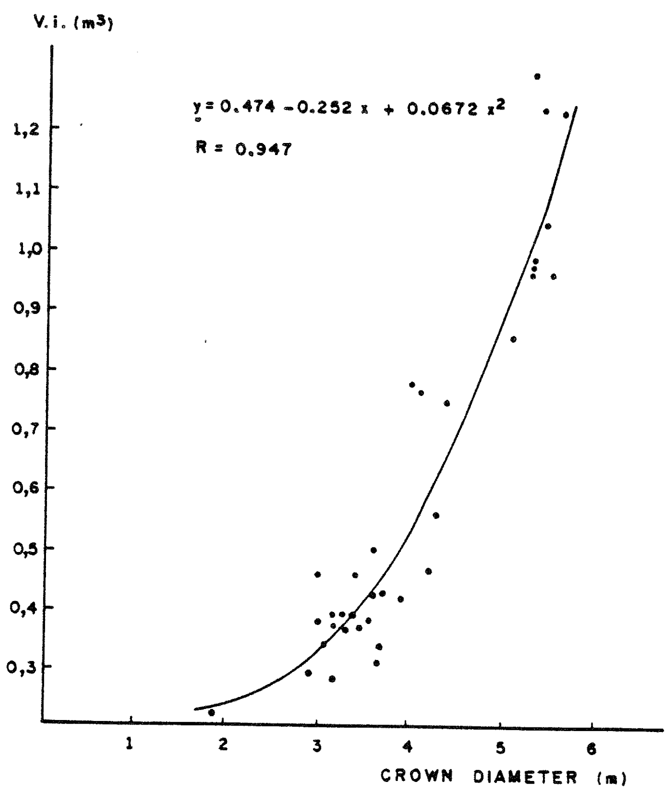

FIGURE 7 - Relation between individual volume (V_i) and crown diameter ($\overline{CD}$).

3.3 Total volume estimates

The best equations to estimate number of trees and individual volume are:

$N = a + bn + cn^2$ R = 0.951

$V_i = d + e\,\overline{CD} + f\,\overline{CD}^2$ R = 0.947

For the total volume estimates the following equation is used:

$$V_t = N \times V_i$$

$$V_t = (a + bn + cn^2) \times (d + e\,\overline{CD} + f\,\overline{CD}^2)$$

$$V_t = a_1 + b_1 n + c_1\,\overline{CD} + d_1 n^2 + e_1\overline{CD}^2 + f_1 n\,\overline{CD} + g_1\,n^2\,\overline{CD} + h_1\,n\,\overline{CD}^2 + i_1\,n^2\,\overline{CD}^2$$

However, in this study only the combination of three independent variables were utilized, because the addition of further independent variables merely increases the amount of computing time.

1) $V_t = -506 + 0.814\,n + 118\,\overline{CD} - 0.00527\,n\,\overline{CD}$ R = 0.790

2) $V_t = -226 + 0.535\,n + 11.3\,\overline{CD}^2 + 0.0719\,n\,\overline{CD}$ R = 0.796

3) $V_t = -272 + 0.000593n^2 + 85.2\,\overline{CD} + 0.076\,n\,\overline{CD}$ R = 0.796

4) $V_t = -114 + 0.000437\,n^2 + 9.07\,\overline{CD}^2 + 0.113\,n\,\overline{CD}$ R = 0.801

5) $V_t = -71.9 + 0.000344n^2 + 1.29\,\overline{CD}^2 + 0.135\,n\,\overline{CD}$ R = 0.804

6) $V_t = -458 + 0.667n + 112\,\overline{CD} + 0.0000500\,n^2\,\overline{CD}$ R = 0.792

7) $V_t = -96.3 + 0.229\,n + 10.4\,\overline{CD}^2 + 0.000184\,n^2\,\overline{CD}^2$ R = 0.806

8) $V_t = -226 + 0.000423n^2 + 88.1\,\overline{CD} + 0.000134\,n^2\,\overline{CD}$ R = 0.800

9) $V_t = -33.9 + 0.000177n^2 + 9.58\,\overline{CD}^2 + 0.000203\,n^2\,\overline{CD}$ R = 0.808

10) $V_t = 27.6 + 0.0000320n^2 + 1.37n^3 + 0.000240\,n^2\,\overline{CD}$ R = 0.811

11) $V_t = -509 + 0.810\,n + 119\,\overline{CD} - 0.00105\,n\,\overline{CD}^2$ R = 0.790

12) $V_t = -206 + 0.606\,n + 9.88\,\overline{CD}^2 + 0.0142\,n\,\overline{CD}^2$ R = 0.795

13) $V_t = -188 + 0.000621\,n^2 + 63.2\,\overline{CD} + 0.0189\,n\,\overline{CD}^2$ R = 0.796

14) $V_t = -54.4 + 0.000531\,n^2 + 6.00\,\overline{CD}^2 + 0.0248\,n\,\overline{CD}^2$ R = 0.799

15) $V_t = -21.5 + 0.000485\,n^2 + 0.807\,\overline{CD}^3 + 0.0276n\,\overline{CD}^2$ R = 0.802

16) $V_t = -467 + 0.770\ n + 106\ \overline{CD} + 0.000832\ n\ \overline{CD}^3$ $R = 0.790$

17) $V_t = -163 + 0.597\ n + 7.22\ \overline{CD}^2 + 0.00370\ n\ \overline{CD}^3$ $R = 0.792$

18) $V_t = -29.9 + 0.000544\ n^2 + 18.9\ \overline{CD} + 0.00598\ n\ \overline{CD}^3$ $R = 0.795$

19) $V_t = 16.1 + 0.000512\ n^2 + 1.27\ \overline{CD}^2 + 0.00657\ n\ \overline{CD}^3$ $R = 0.795$

20) $V_t = 24.5 + 0.000503 n^2 + 0.169\ \overline{CD}^3 + 0.00664\ n\ \overline{CD}^3$ $R = 0.795$

The equation (10) is the best and should be used for the construction of a stand aerial volume table.

The use of eletronic computer makes it possible to test these equations with different combinations of variables with the object of selecting the best fitting equation.

It was verified that only two factors measured are sufficient to obtain a suitable volume estimate when multiple regression analysis is utilized.

The total volume estimate of *Araucaria angustifolia* stands was made with good accuracy due to its age (16 to 50 years old), whose fact means that unless more than one thinning had been executed, and the data collection on aerial photographs was facilitated.

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BIBLIOGRAPHY

AOKI, H. et alii. 1976. Desenvolvimento de sistema semi-automático para inventários madeireiros. *Silvicultura em São Paulo* 10:137-147.

CHYO, M. & AOKI, H. 1983. Inventário florestal através da utilização de fotografias aéreas. In: CONGRESSO FLORESTAL BRASILEIRO, 4. Belo Horizonte - MG.

GALLOZZI, A. et alii. 1979. Inventário florestal do Estado de São Paulo. *Bol. Técn. IF.*, São Paulo, 30: 1-26.

GUIDONI, B.A. & KONECSNI, I. 1982. Reflorestamento de *araucaria angustifolia* (Bertolini) O. Kuntze na Companhia Melhoramentos de São Paulo - Indústria de Papel-Caieiras. In: CONGRESSO NACIONAL SOBRE ESSÊNCIAS NATIVAS, I, Campos do Jordão - SP. p.732 - 746.

LOETSCH, F. & HALLER, K.E. 1973. Forest inventary. 2 v. München Germany.

SERRA FILHO, R. et alii. 1974. Levantamento da cobertura vegetal natural e do reflorestamento no Estado de São Paulo. *Bol. Técn. IF.*, São Paulo, 11: 1-53.

SERRA FILHO, R. et alii. 1975. Levantamento da eucaliptocultura e pinocultura no Estado de São Paulo, *Bol. Técn. IF.*, São Paulo. 17:1-80.