SOIL ANALYSIS FOR SITE EVALUATION UNDER TROPICAL AND SUBTROPICAL CONDITIONS

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SUMMARY

Results of chemical and physical soil analysis for the evaluation of site and nutritional growth conditions of Araucaria-plantations (Araucaria angustifolia, Bert.O.Ktze) in Central and Southern Brazil are shown and discussed together with other site and growth parameters determined on these sites.

From this, further conclusions are drawn on a general methodological approach for the quantitative determination of site factors with special emphasis on soil studies under tropical and subtropical conditions.

ZUSAMMENFASSUNG

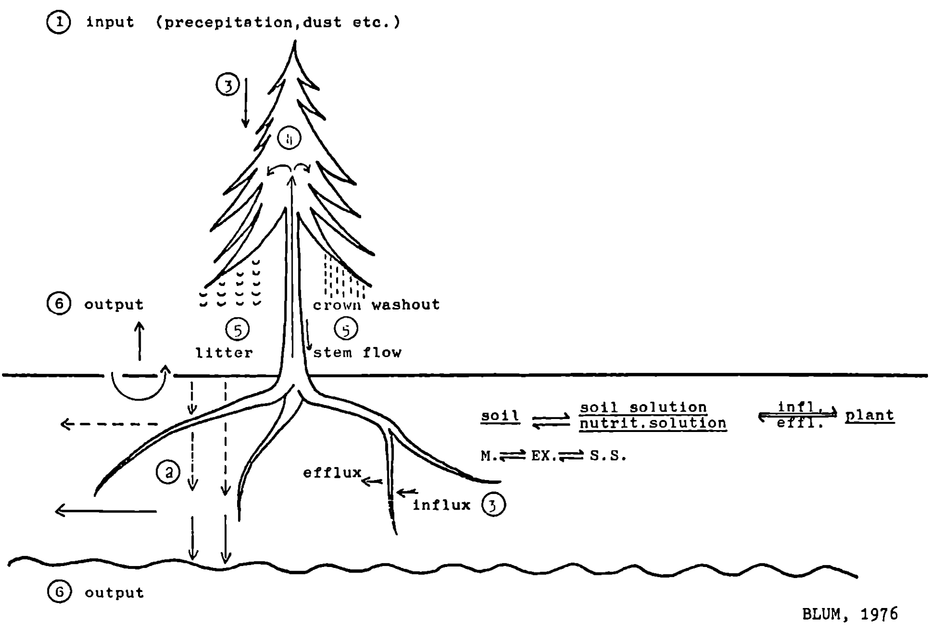
Es werden die Ergebnisse chemischer und physikalischer Bodenuntersuchungen zur Bestimmung von Standorts- und Wachstumsbedingungen von Araukarien-Aufforstungen (Araucaria angustifolia, (Bert.)O.Ktze) in Zentral- und Südbrasilien dargestellt und zusammen mit weiteren Ergebnissen von Standorts- und Wachstumsuntersuchungen in diesem Gebiet diskutiert.

Daraus werden weitere Aussagen bezüglich eines allgemeinen methodologischen Ansatzes für die quantitative Bestimmung von Standortsfaktoren unter spezieller Berücksichtigung von Bodenuntersuchungen unter tropischen und subtropischen Bedingungen abgeleitet.

I N T R O D U C T I O N

Soil analysis for site evaluation is concerned with the soil – soil solution (nutrient solution) – plant – relationship. Within the soil, mineral (M.) and exchange soil characteristics (Ex) can be distinguished in a first approximation (see fig.1 and ULRICH, 1968).

FIG.: 1 CYCLE OF NUTRITIVE ELEMENTS IN FOREST ECOSYSTEMS



The same relationship is shown schematically in fig.2 where the material and functional relationship between the soil phases and the root system are described.

FIG. 3:

ANNUAL VARIATIONS OF SOIL CONDITIONS
CAUSED BY CLIMATIC FACTORS
(SCHEMATICALLY SHOWN BY SOIL HUMIDITY)

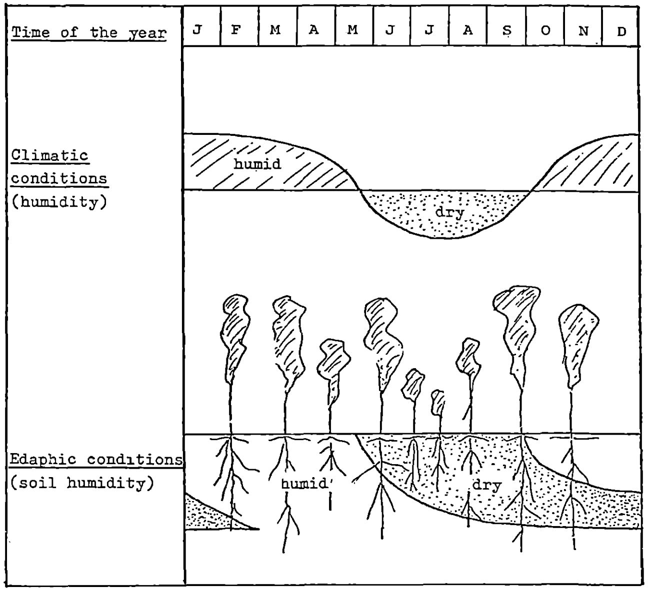
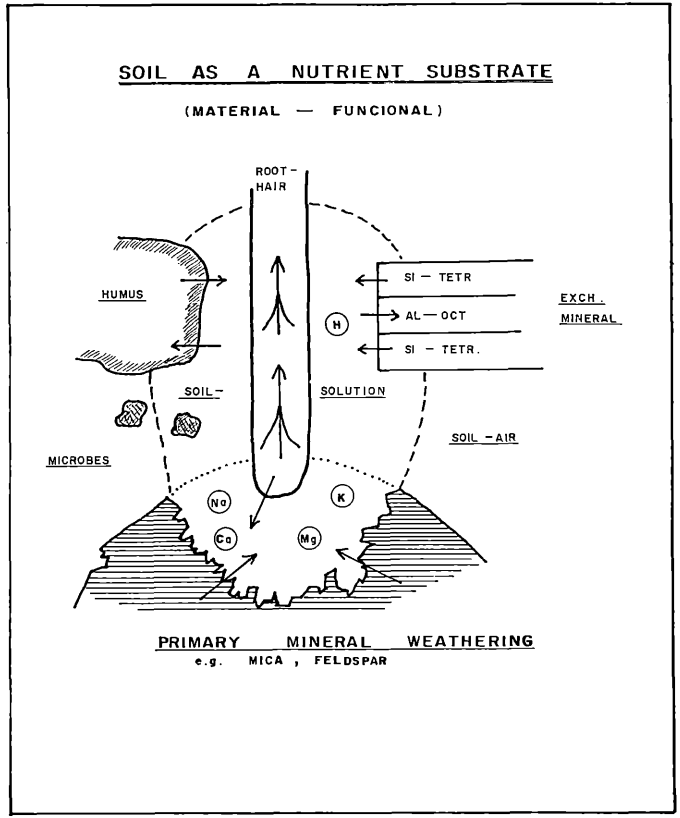


FIG. 2:



Interrelations in this soil - plant system are only possible through the liquid soil phase or soil solution (nutrient solution) and therefore highly dependent on soil physical as well as climatic conditions, see schematical appresentation of "Annual variation of soil conditions caused by climatic factors" in fig.3.

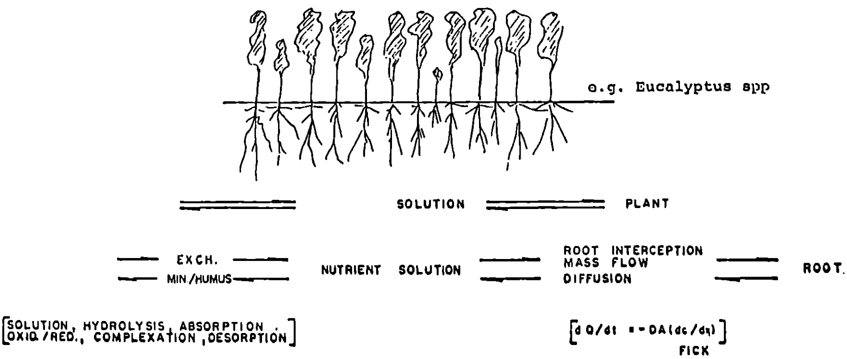
Because of this, soil - plant interrelation is not static but highly dynamic and varying in its intensity and in relation with time. But not only soil humidity and its influence on the soil solution or nutrient solution are important, because nearly all processes in this system are highly influenced by energy input, i.e. soil temperature. This is true for soil chemical and physico-chemical reactions and all processes determining nutrient uptake by the plant - root - system.

In order to emphasize this hypothesis, the nutrient uptake as a thermodynamic process is described schematically in fig.4. In this figure an attempt was made to show all processes in the soil, liberating nutrients to the soil or nutrient solution (left side of fig. 4) e.g. solution, hydrolysis, absorption, desorption, oxidation, reduction, complexation and all processes involved in nutrient uptake by the plant - root - system (right side), e.g. root interception, mass flow and diffusion.

FIG. 4:

NUTRIENT UPTAKE AS A THERMODYNAMIC PROCESS

(RELATION QUANTITY INTENSITY)



In this figure microbiological and biochemical processes are not shown, which are also of high importance in the dynamics of soil - plant interrelations.

All these processes described schematically in fig. 4 as well as microbiological and biochemical processes are directly or indirectly influenced by the energy level or temperature in the soil.

This cannot be discussed in detail here (see also BLUM, 1979) but it can be presumed that all physico-chemical processes between soil and soil solution as well as the diffusion and root interception are directly influenced by temperature. Moreover, root interception and mass flow will be influenced indirectly either through soil or through air temperature in the above ground biomass (compare e.g. transpiration and mass flow).

Therefore, these interrelations are described as thermodynamic processes.

Based on the rule of VAN´ T HOFF, indicating that the velocity of a physico-chemical reaction is at least doubled with the raise of temperature by 10°C, it can be presumed, that all processes in the soil - plant system, which are directly influenced by temperature are quicker at higher temperatures, due to the energy available in the soil.

Unfortunately, little or nearly no research work has been done so far on the investigation of these presumably highly important influences of energy on the soil - plant system or in other words, the explanation of plant growth as a function of energy factors in the soil (see also MONTEITH, 1979).

From the above cited presumptions several general conclusions can be drawn:

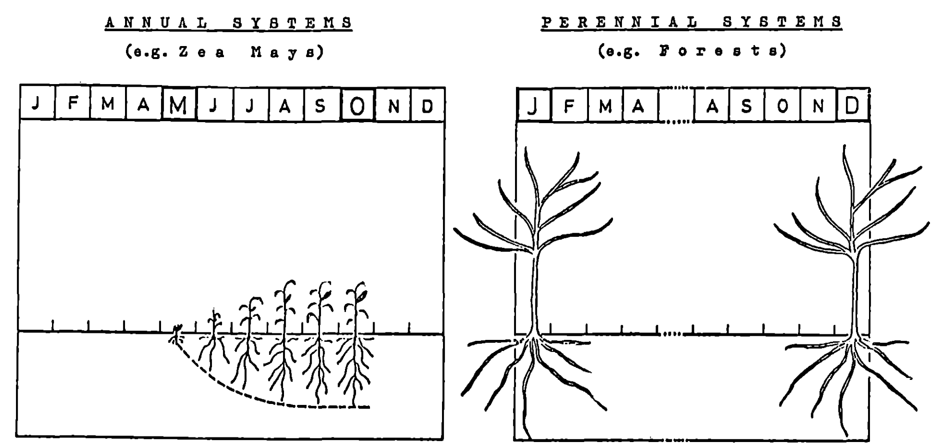
- Because of the large amount of energy available in tropical and subtropical soils through soil temperature, the velocity of the above schematically described processes (and others as well) must be higher in these soils than in temperate climatic conditions, thus raising the hypothesis that nutrient uptake and cycling sustaining plant growth, must be quicker.

- Therefore, plant growth, especially of plants with low nutrient demands in relation to agricultural crops such as forest species, is still possible on very "poor" sites, due to the velocity of the nutritive processes.
- If therefore the velocity or intensity of processes can be presumed as highly important factors, the time of participation in these processes is a further important parameter.

This means that perennial plants with perennial root systems are continuously participating in these processes (after the establishment of a plant cover) and therfore also very small, but rapid or very rapid fluxes, as e.g. under tropical and subtropical conditions, can sustain such perennial plant growth.

On the other side, annual plant systems, as e.g. most of the agricultural crops, need annually new energy for the establishment of a new root system and they participate therefore only temporarily in the nutrient fluxes, see fig.5.

FIG. 5:
ANNUAL CYCLE OF PLANT GROWTH AND NUTRIENT UPTAKE



Therefore, agricultural crops normally need much "better" soil conditions for sufficient growth than perennial plants.

If we compare tropical or subtropical with temperate climatic conditions it can also be presumed, that due to the above cited hypothesis, certain forest or agricultural plant systems can still grow in the tropics or subtropics under soil conditions under which they would not develop in temperate climatic regions.

Within the same climatic region, due to the temporarily different participation of perennial (e.g.forest) plants in the soil - plant - processes (compared with annual crops), the latter need better soils than perennials.

- From this, further conclusions can be drawn on the methodological approach for soil and site evaluation. Under tropical and subtropical soil conditions with higher velocity of soil-plant nutrition processes, a single (or singular) soil analysis, especially by soil extraction methods, is only of very limited or even without any value for the evaluation of soil - plant growth relations.

  This is true for all plant systems, perennial and annual ones, but especially for perennials, e.g. forest plants.

- Therefore it seems necessary to concentrate under such soil conditions on indirect evaluation e.g. of soil physics, which condition water availability, physico-chemical and biochemical processes. Also indicated are other methods for the analysis of soil parameters directly influencing plant growth and nutrient availability, e.g. soil analysis by total digestion.

  It can be stated here, that nearly all soil analytical methods used in the tropics and subtropics were established in regions with temperate climatic conditions and developed for those conditions. The applicability of these methods under tropical and subtropical soil and site conditions could not be prooved until today.

- This raises the question about a general definition of soil and site fertility under tropical and subtropical conditions. What is a fertile soil and under which conditions?

  There seems to be much confusion about the definition of fertility of tropical and subtropical soils, due to the fact, that fertility cannot be defined by a single chemical soil analysis, but needs a complex definition and analysis of thermodynamic processes in the soil which were described schematically above and which are related to other complex processes such as plant growth.

In the following an attempt is made to investigate soil and site evaluation methodology under tropical and subtropical conditions on established stands of Araucaria angustifiolia (Bert.)O.Ktze in Central and Southern Brazil.

M E T H O D O L O G Y

Investigations were performed in two steps.

In a first step 260 selected established plantations of Araucaria angustifolia (Bert.)O.Ktze were investigated 1973-74 (De HOOGH and DIETRICH, 1979).

In a second step, based on the preliminary results, De HOOGH selected in the same investigation area 26 plots for further detailed soil, site and other investigations.

The investigated area of about 960 x 700 km of extension is shown in figure 6. The soil types within this area are very different and listed in table 1.
Also other physiogeographical parameters as climate, altitude, latitude etc. are varying considerably within the investigated region as well as land use and the vegetation cover of the sites before the establishment of the Araucaria stands.

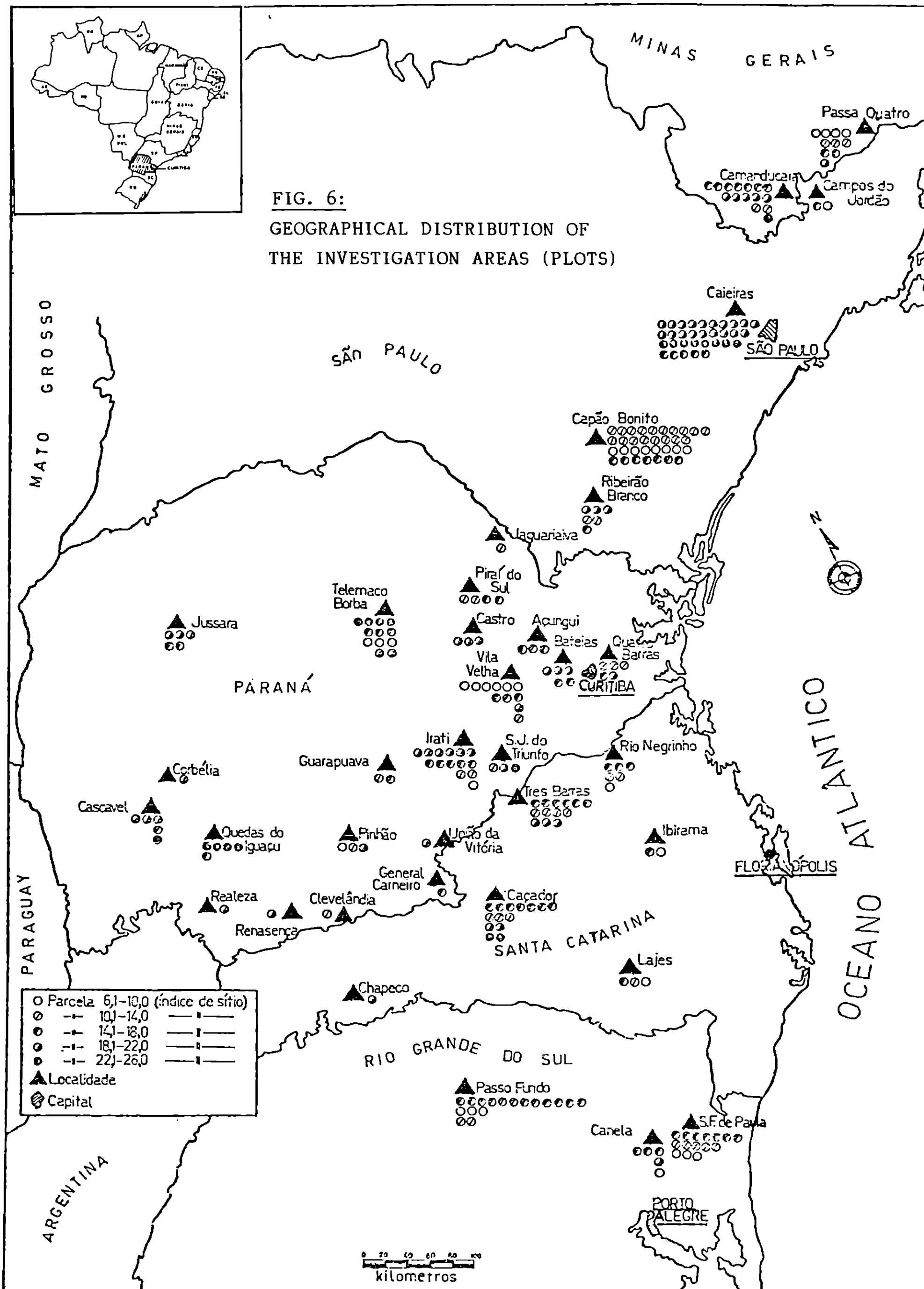


FIG. 6:
GEOGRAPHICAL DISTRIBUTION OF THE INVESTIGATION AREAS (PLOTS)

R.J. de HOOGH and A.B.DIETRICH, 1979

TABLE 1: SOIL TYPES OF THE RESEARCH AREAS, CLASSIFIED ACCORDING TO THE BRAZILIAN SOIL CLASSIFICATION SYSTEM (SIMPLIFIED).

Soil Types	Substrate (Rock Parent Material)
1. Red-yellow Latosol	granite/gneiss
2. Dark-red Latosol	claystone/siltstone
3. Dark-red Latosol	sandstone
4. Latosol Roxo	basalt
5. Red-yellow Podzolic	claystone/siltstone
6. Reddish-brown Lateritic	basalt
7. Dystrophic Cambisol	granite/gneiss
8. Dystrophic, very humid Cambisol	granite/gneiss
9. Dystrophic, humic Cambisol	claystone/siltstone
10. Eutrophic, humic Cambisol	granite/gneiss
11. Dystrophic Litosol	basalt
12. Eutrophic Litosol	basalt

The methods of soil and site evaluation in the first step 1973/74 are shown in table 2 and the site index curves obtained in fig. 7 (see also De HOOGH and DIETRICH, 1979). In contrast to this, in the second investigation of 26 selected plots 1978-79, De HOOGH. in preparation, used other soil and site investigation methods:

- only stands aged from 22-28 years were investigated,

  tree growth was analyzed by stem analysis (Site Index (S.I.) Periodical Annual Increment (P.A.I.) during the last 10,5,3, 2 years and Current Annual Increment C.A.I.),
- chemical foliar analysis including micro-elements was performed,

TABLE 2: SITE EVALUATION OF 260 ARAUCARIA STANDS, 1973-1974 (FIRST STEP) METHODS OF DATA COLLECTING AND SOIL AND SITE ANALYSIS (De HOOGH and DIETRICH, 1979).

FIELD DATA:

Climate: mean annual rainfall
temperature

Topography: altitude
latitude
exposition
slope degree

Stand:
- vegetation cover before planting
  - natural forest
  - degraded nat.forest
  - abandoned agr.land
  - cultivated land
  - natural grassland
- initial spacing
- age of the stand
- total height
- dominant height
- diameter at breast height

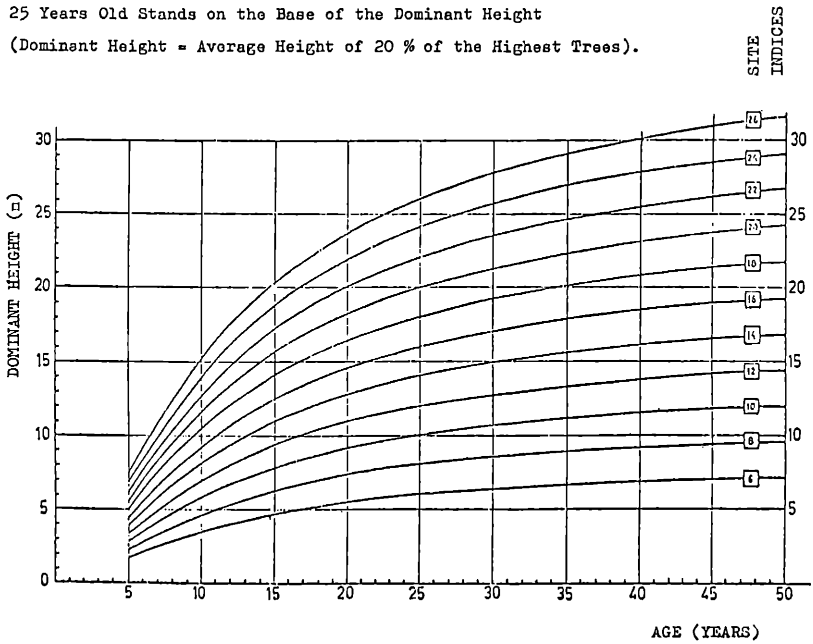
Soils:
- soil description
- sampling 0-25 cm (1 sample)

LABORATORY DATA:

Stand:
- site index (site quality curves)

Soils:
- pH (H_2O/KCl)
- Exch. K, Ca, Mg, Al
  (1nKCl/0,025HCl+H_2SO_4/1nCa-acetate - Extraction)
- "available" P
  (0,05nHCl+0,025nH_2SO_4) - Extraction
- CEC
- Base saturation e.o.
- particle size distribution

FIG. 7: Site Evaluation of Araucaria angustifolia - 1974
Site Index Curves with 2 m Intervals Calculated for
25 Years Old Stands on the Base of the Dominant Height
(Dominant Height = Average Height of 20 % of the Highest Trees).



- soils were sampled to 100 cm of depth at 5 and 10 cm intervals and analyzed by total digestion including micro-elements,
- also physical soil characteristics were determined (particle density, bulk density, total porosity, soil moisture, water retention capacity available water between the wilting point, pF 4,2 and field capacity pF 2,5).

All data obtained in the first investigations 1973/74 and in the second phase 1978/79 were evaluated by the same multiple regression analysis with a forward stepwise selection procedure with the linear model:

S.I. a + b x + b x ....b x)

(S.I. Site Index, x Site Factor; the site index (site quality curves), based on dominant height (in m) and age (in years), is shown in fig. 7).

R E S U L T S

In the following, results of the regression analysis of soil data and all sampled/analyzed data are shown for the phase 1 (1973/74) and phase 2 (1978/79) separately.

Results of the first investigation 1973/74 (De HOOGH and DIETRICH, 1979).

Site index over soil analysis data and site index over all sampled/analyzed data for all 260 plots and 121 selected plots are shown in table 3.

These data indicate, that analysis of exchangeable cations, cation exchange capacity (C.E.C.) and other site chemical data explain only about 20-25 % of the total variations.
In contrast to this, other parameters as vegetation cover before establishment of the stand (e.g. grassland, abandoned agricultural land) explain about 50 % of the variations, even considering the fact, that such caracteristics are not very specific and cannot explain tree growth by a connection of cause and effect.

Results of the second investigation 1978/79 (see also De HOOGH, in preparation).

Site index over chemical soil characteristics (total element content % and total element content/ha) and periodical annual increment of the last 3 years over chemical soil characteristics are given in table 4.

Site index over physical soil characteristics and site index over physical and chemical soil characteristics as well as site index over vegetation type before planting are shown in table 5.

The results of the second investigation period 1978/79 reveal that soil chemical analysis by total digestion explains about 30-40 % of the growth variation and the sampling procedure enables to determine diagnostic horizons in relation to the soil nutrition status.- Correlations between site index and soil

Table 3: Results of Regression Analysis with Stepwise Forward Selection Procedure for 260 (121) Araucaria-Plots 1973-74.

	Step:	Variable added:	% Variations explained/step ($100xR^2$):	Significance (of final regr.coeff.):
1. Site Index over Soil Analysis Data:	1	Exch.Ca+Mg (me/100g)	13,5 (15,7)	+ + (+ +)
	2	Depth A-Hor. (dm)	17,5 (21,3)	+ + (+ +)
	3	Exch. K (me/100g)	19,9 (27,1)	+ + (+ +)
	4	Total soil depth (dm)	20,7	+ +
	5	Exch.Al (me/100g)	21,6 (29,0)	+ + (+)
2. Site Index over all sampled analyzed data (all 260 plots):	1	Exch.Ca+Mg (me/100g)	13,5	+ +
	2	Latitude	17,7	+ +
	3	Depth of A-Hor. (dm)	21,7	+ +
	4	Exch.Al (me/100g)	23,5	+ +
	5	Initial spacing	25,3	+ +
	6	Exch. K (me/100g)	26,9	+ +
	7	Mean annual temp.	27,8	+ +
	8	Mean annual precipitation	28,3	+ +
	9	Lang´s climatic index	32,0	+ +
3. Site Index over all sampled/analyzed data (121 selected plots):	1	Grassland	24,0	+ +
	2	Abandoned agric. land	50,2	+ +
	3	Exch. Ca+Mg (me/100g)	53,8	+ +
	4	Exch. K (me/100g)	57,3	+ +
	5	Latitude (°)	58,6	+ +
	6	CEC (me/100g)	60,1	
	7	Cultivated land	61,1	+
	8	Secondary forest	61,8	+ +
	9	Initial spacing (m^2)	62,8	+ +

Table 4: Results of Regression Analysis with Stepwise Forward Selection Procedure for 26 Araucaria Plots 1978 - 79

(Non-significant Regressions are not shown)

	Soil depth:	Step:	Variable added:	% Variation explained: ($100xR^2$)	Significance (of final regr.coeff.):
1. Site Index over Chemical Soil Characteristics (Total element content %)	0 - 20 cm	1	pH (KCl)	13,1	+ +
		2	Fe	29,6	+ +
		3	Mn	42,3	+ +
	0 - 50 cm	1	pH (KCl)	12,7	+ +
		2	Fe	28,9	+
	0 -100 cm	1	pH (KCl)	14,1	+ +
		2	Fe	31,2	+
2. Site Index over Chemical Soil Characteristics (Total element content/ha)	0 - 20 cm	1	Zn	17,9	-
		2	Fe	23,6	+
		3	pH (KCl)	35,4	+
	0 - 50 cm	1	Zn	16,4	
		2	Fe	22,1	+ +
		3	pH (KCl)	30,9	+ +
	0 -100 cm	1	Cu	14,3	+ +
		2	pH (KCl)	17,7	+ +
		3	Ca	36,5	+
3. Periodical Annual Increment of last 3 Years over Chemical Soils Characteristics		1	C/N	13,6	+ +
		2	Al	23,5	+ +
		3	pH (H_2O)	36,6	+

Table 5: Results of Regression Analysis with Stepwise Forward Selection Procedure for 26 Araucaria Plots 1978–79

(Non-significant Regressions are not shown)

	Step:	Variable added:	% Variations explained/step ($100xR^2$):	Significance (of final regr.coeff.):
1. Site Index over Physical Soil Characteristics	1	Porosity (50–100cm)	17,4	+ +
	2	Available H_2O(50–100cm)	36,8	+ +
2. Site Index over all Physical and Chemical Soil Characteristics (and Latitude):	1	Porosity (50–100cm)	17,4	+ +
	2	Avail.H_2O (50–100cm)	36,8	+ +
	3	pH(KCl) (0–20cm)	47,1	+ +
	4	Ca t/ha (0–100cm)	56,1	+ +
	5	Al %	63,0	+ +
	(6	Latitude	68,7	+)
3. Site Index over Vegetation type before Planting	1	Natural grassland	23,3	+ +
	2	Abandoned agric.land	46,5	+ +

characteristics and periodical annual increment and soil characteristics show no significant difference, except that in the case of site index pedogenetic factors seem to reflect the more permanent physical and chemical properties of the soil whereas in the case of periodical annual increment microbiological activities seem to interfere to a significant extent (see C/N-relation).

The evaluation of physical soil characteristics reveals that about 37 % of growth variation can be explained by only two parameters: total soil porosity and soil water retention capacity between pF 4,2 and 2,5 ("available" H_2O); see table 5.

Regression analysis of site index over all physical and chemical soil characteristics indicates, that 63 % of all variation can be explained by 5 parameters.

In relation to this, field observations on land use or vegetation cover before planting "explain" about 47 % of all variation in tree growth.

D I S C U S S I O N

Comparing these results with the factors discussed in the introduction, some conclusions on methodology of soil and site evaluation under tropical and subtropical conditions can be drawn:

- Extraction analysis for chemical soil evaluation under these conditions show no satisfactory results.
- Soil analysis by total digestion shows better correlations to plant growth in relation to the availability of micronutrients.
- Physical soil characteristics (as indirect parameters for soil chemistry and microbiology as well as direct indicators for water supply and aeration) explain to nearly the same extent the observed variation in plant growth as chemical soil analysis by total digestion. Physical and chemical characteristics together explain more than 60 % of all variation.

- In contrast to this, results from simple field observations on land use and vegetation cover before stand establishment were associated with about 47 % of all variation.

These conclusions and general results are not much satisfactory, but they confirm the above cited presumptions (see introduction) on the thermodynamics of the processes in soil plant systems of the tropics and subtropics as well as the hypothesis on the methodological approach. They indicate the need for further research work in the near future.

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