Mineral Deficiencies of Forest Trees in Yucatan (Mexico) and Consequences for Land-Use[1]

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ABSTRACT

On calcareous shallow, stony soils derived from tertiary limestone in the Yucatan peninsula (Mexico), forest trees develop deficiency symptoms such as reduced growth, loss of leaves, dieback of shoots and different patterns of chlorosis. Detailed observations combined with foliar analysis allow a first diagnosis, as shown by some of the nutrient concentrations found in leaves of deficient trees which are supposed to be below the critical level for adequate nutrient supply. *Leucaena leucocephala:* 0.10% P, 9 ppm Mn; *Brosimum alicastrum:* 1.44% N, 0.06% P; *Gmelina arborea:* 8 ppm Zn; *Tectona grandis:* 24 ppm Mn, 0.13% P; *Manilkara zapotilla:* 10 ppm Mn; *Pinus caribaea:* 20 ppm Mn; *Swietenia macrophylla:* 1.00% N, 0.06 - 0.08% P, 13 ppm Mn. Specific difficulties in smallholder land-use and reforestation may be attributed to these deficiencies and could be overcome by diversified management techniques based on traditional agroforestry practices. Under large-scale forest management conditions, however, soil evaluation and tree species selection should be considered a major point of emphasis.

COMPENDIO

En suelos calcáreos pedregosos, derivados de caliza terciaria en la península de Yucatán, los árboles forestales desarrollan síntomas de deficiencia como crecimiento reducido, pérdida de hojas, marchitamiento de retoños y distintas formas de clorosis. Observaciones precisas combinadas con el análisis de hojas permiten establecer un primer diagnóstico. Así algunas de las concentraciones en nutrimentos, encontradas en hojas de árboles en estado achacoso, están supuestamente bajo su nivel crítico de sustento adecuado: *Leucaena leucocephala* 0.10%, 9 ppm Mn; *Brosimum alicastrum,* 1.44% N, 0.06% P; *Gmelina arborea,* 8 ppm Zn; *Tectona grandis,* 24 ppm Mn, 013% P; *Manilkara zapotilla,* 10 ppm Mn; *Pinus caribaea* 20 ppm Mn; *Swietenia macrophylla* 1.00 N, 0.06 - 0.08% P, 13 ppm Mn. Dificultades específicas de la explotación campesina y la reforestación podrían estar asociadas a esos problemas. Se vencería esas dificultades con técnicas distintas, basadas en prácticas agroforestales tradicionales. De todos modos se debería tomar en consideración, en el caso de plantaciones grandes de árboles, la evaluación de suelos y la mejor selección de las especies.

INTRODUCTION

Forest plantations are often established on marginal sites unsuitable for an efficient continued crop production. This may result in reduced vitality and yields or even in a partial breakdown of the plantation. Mineral deficiency symptoms allow foresters to recognize and prevent such tendencies. The present study seeks to point out such limitations in mineral supply in central Yucatan. Foliar analysis is used for their identification. The results are discussed in terms of adapted land-use management.

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MATERIALS AND METHODS

Site description

Field studies were carried out in the central and southeastern part of the Yucatan peninsula (Fig. 1), a semi-humid tropical area with an average precipitation between 1000 mm and 1400 mm, and a rainy season extending from May to November. Tertiary limestones form the main parent material. Distinct catenas have developed as a result of intensive land use and erosion, dating back to the Mayan period (about 1000 B.C. - 1200 A.D.). Rendzic Leptosols dominate on hills and upper slopes whereas grey and brown-to-red Eutric Vertisols occur at the bottom. A wide variety of intermediate forms, partly with weakly developed cambic horizons cover the lower slopes. Table 1 details soil properties of such a typical catena near Oxkutzcab.

The soils in slope positions have a high stone content and a pore volume of more than 60 per cent; $pH(CaCl_2)$ values of the A horizon are 7.5 - 7.7. Also CEC (44 meq x 100^{-1} g soil) and base saturation (100%) are high. Vertisols at the bottom of slopes have more than 70 per cent clay in the subsoil and porosity ranges between 56 and 66 per cent. Only in the A horizon is pH above 7, whereas in the subsoil horizons pH values between 5.3 and 5.8 have been determined. The field capacity (60 - 15 000 hPa) of all soils in low (4.5 - 8.9 Vol%). X-ray diffraction

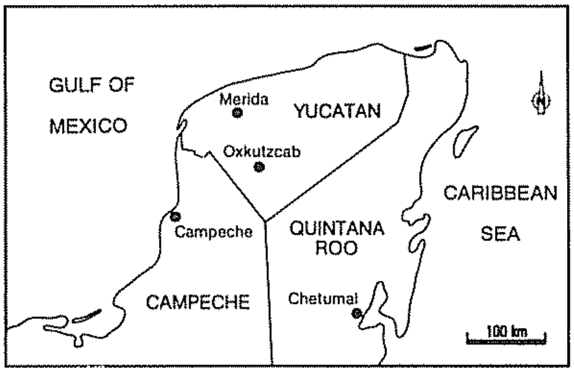

Fig. 1. The Peninsula of Yucatan showing the two sites under study near Oxkutzcab and Avetumal.

Table 1. Properties of a representative soil catena near Oxkutzcab.

Relief. incli-nation	Profile No.	Horizon depth (cm)	Soil description	Stoniness (%)	Texture (%) Sand	Silt	Clay	Hydraulical conductivity k_f(cm sec^{-1})	Bulk density (g cm^{-3})	Pore volume (%)
upper slope 4° N	Rendzic Leptosol 3	Ah 0-15	black, crumby loose structure, many fine roots	60	7	44	49	7.1 x 10^{-4}	0.93	63
		AhCv 15-45	grey black, (sub-) angular, loose, may fine roots, limestone	90	16	46	38	n.d.	n.d.	n.d.
lower slope 2° N	Calcaric Phaeozems 2	Ah 0-25	black, crumby loose structure, many fine roots	30	13	46	41	6.2 x 10^{-4}	0.91	64
		BCv 25-75	reddish white, crumby loose structure, only few fine roots, partly hard limestone	75	n.d	n.d.	n.d.	n.d.	n.d.	n.d.
bottom 0°	Eutric Vertisol 1	Ah 0-15	dark grey, angular blocky, dense structure, many fine roots, some small limestone fragments	tr.	3	39	58	5.3 x 10^{-4}	0.85	66
		AB 15-32	reddish black, blocky structure, stress cutans, cracks, some fine roots	tr.	2	25	73	4.7 x 10^{-4}	1.06	60
		B 32-75+	brown-red, blocky dense structure, stress cutans, cracks, some fine roots	tr.	2	22	76	3.1 x 10^{-4}	1.16	56

Continuation Table 1. Properties of a representative soil catena near Oxkutzcab.

Reflef. incli-nation	Profile No.	Horizon Depth (cm)	Soil description	Field capacity Vol %	pH $CaCl_2$	Corg %	Nt %	CEC meq 100 g^{-1}	Base saturation %
upper slope 4° N	Rendzic Leptosol 3	Ah 0-15	black, crumby loose structure, many fine roots	7.4	7.46	3.14	0.47	44.4	100
		AhCv 15-45	grey black. (sub-) angular, loose, many fine roots, limestone	n.d.	n.d.	n.d	n.d	n.d.	n.d.
lower slope 2° N	Calcaric Phaeozems 2	Ah 0-25	black, crumby loose structure, many fine roots	7.7	7.73	2.03	0.30	44.1	100
		BCv 25-75	reddish white, crumby loose structure, only few fine roots, partly hard limestone	n.d	7.61	0.71	0.08	22.9	100
bottom 0°	Eutric Vertisol 1	Ah 0-15	dark grey, angular blocky, dense structure, many fine roots, some small limestone fragments	8.9	7.10	2.75	0.24	36.4	98
		AB 15-32	reddish black, blocky structure, stress cutans, cracks, some fine roots	6.1	5.79	1.27	0.13	25.6	72
		B 32-75+	brown-red, blocky dense structure, stress cutans, cracks, some fine roots	4.5	5.35	0.67	0.09	23.7	68

n.d.: not determined tr: traces

(XRD) analysis shows a dominance of kaolinite in all soils (Fig. 2). The broad peaks near 14 Å in soil 2, which expand to 18 Å after glycerol treatment, are probably due to vermiculite-smectite clay mineral of low crystallization.

Most of the trees under study are growing on shallow Rendzic Leptosols. These marginal sites are widespread all over the peninsula and as they are inappropriate for any conventional agriculture, are often reforested.

To date there are two types of tree planting with promising prospects: a commune-orientated programme of forest management based on natural regeneration and supportive planting, particularly in the southeastern part of the peninsula; and individual, small-scale reforestation and establishment of traditional tree gardens in the central area of Yucatan. Our sample plots near Chetumal and Oxkutzcab (Fig. 1) belong to both of these areas. Typical trees are the

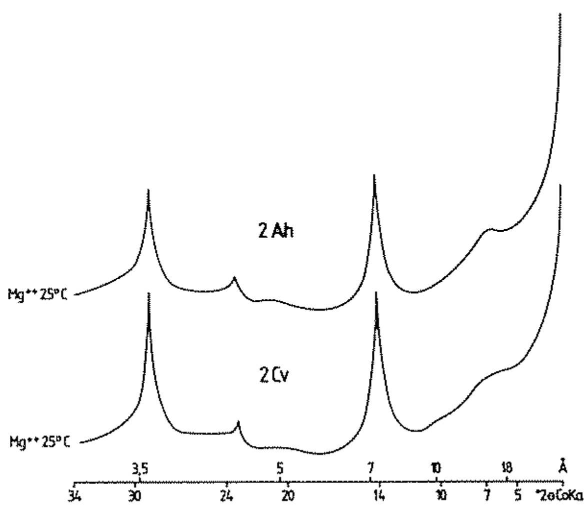

Fig. 2. Results of X-ray diffraction analysis demonstrated by an example of soil 2.

native *Brosimum alicastrum*, *Leucaena leucocephala*, *Pinus caribaea* or *Swietenia macrophylla*, as well as the exotic *Gmelina arborea* and *Tectona grandis*. In family gardens fodder (*Brosimum*, *Leucaena*) and fruit-bearing trees (mango, avocado, coco, and citrus) are preferred by farmers.

Foliar sampling, chemical and physical analyses

Leaf samples were taken at the end of May from the upper part of the crown of five to ten trees. As usual, the first mature leaves below the tip of branchlets were collected. After drying (65°C), samples were mixed and ashed (550°C). Two grammes of ashed tissue was dissolved in 50 ml 10% HCl, brought to 100 ml and K, Ca, Mg, Al, Fe, Mn, Cu, Zn were measured directly with atomic absorption. N was determined after Kjeldahl with Büchi apparatus No. 320, P and B colorimetrically with molybdenum blue and 1,1-dianthrimide, respectively. Clay mineral in soil samples were analysed using XRD and Cokα-radiation. Physical properties were analysed according to Hartge (6), and texture with an areometer (8). For soil chemical properties see Zech (18). Soils were classified according to FAO (4).

RESULTS AND DISCUSSION

Table 2 provides the results of foliar analyses. On eight species of trees (14 samples) foliar levels for optimal growth and critical levels for the appearance of visual deficiency symptoms are only little known for most deciduous tropical tree species (17), our interpretation is somewhat tentative. But the detailed study of symptoms, combined with a careful interpretation of the foliar data and site properties, should give reliable results and a first clue to further investigations.

Near **Oxkutzcab**, *L. leucocephala* (Table 2, sample 1) planted on soils with a pronounced calcic horizon of 25 cm depth and pH values ($CaCl_2$) of 7.73 in the surface layer, show dull green, small leaves. The crowns are narrow and only few leaves are retained. Trees suffer from leader dieback. According to Table 2, foliar phosphorus is very low (0.10%). On the same site *Leucaena* also suffers from chlorosis of the younger leaves at the end of the shoots. Some leaves are completely yellow, others reveal interveinal chlorosis. Foliar analysis indicates primary lack of manganese. Mn levels are only 9 ppm, whereas in sample 1 with green leaves, 28 ppm were recorded. In Middle Europe tree species are supposed to suffer from manganese deficiency when leaf concentrations are below 20 ppm (7, 13, 14). In addition, sample 2 has only 1.98% foliar nitrogen. Problems relating to B nutrition could not be verified. According to these results, *Leucaena*, which is supposed to be well adapted on alkaline and neutral soils, does not grow vigorously on these shallow soils. We assume that P and Mn nutrition are inadequate. Chlorosis and loss of foliage also seems to be enhanced by water stress. Another tree species native to Yucatan is *B. alicastrum* ("ramón"). In northeastern Mexico pure stands occur on steep slopes and calcareous soils. Studies have revealed that this multipurpose tree was already widely used and cultivated by the Maya (11). In green leaves we analysed 0.08 - 0.15% P (Table 2, samples 3 - 5), the lower values are typical for the poorly growing two-year-old individuals (Table 2, sample 4). However, they show no chlorosis, despite the fact that only 9 ppm foliar Zn and 0.08% foliar P could be found. But the ten-year-old and approximately 6 m high trees (Table 2, sample 6), develop chlorotic leaves, especially in the lower part of the crown. We believe that these trees suffer from N and P deficiencies because only 1.44% N and 0.06% P could be found in their leaves. Additionally, the K/Ca ratio is only 0.27 which seems far too narrow.

Leucaena and *Brosimum* are valuable trees for agroforestry systems. Usually, *Leucaena* is known for its raw protein-rich fodder, higher growth rate and high biomass production. According to our observations near Oxkutzcab, *Brosimum* seems superior on stony shallow sites, probably due to its widely reported drought tolerance (9). The foliage is highly appreciated by animals and its digestibility is superior to that of *L. leucocephala* (11). Due to its evergreen status, it is often the principal fodder for livestock during drier months. The wood is used for furniture and fuel.

With regard to crude protein (cp) and digestible crude protein (dcp), values between 15.2 per cent (10.1) and 24.2 per cent (18.5) (dry matter) indicate that healthy trees of both species can be a source of high quality fodder (12). On the other hand, the demands of cows are not always covered for P, Mn and mainly Zn because foliar levels are often below the critical values (12) of 0.12% P, 50 - 60 ppm Mn and 30 - 60 ppm Zn. Also the Ca/P ratios, which should lie between 1.0 and 1.7 for tropical livestock, are too high (14 - 53) (1). Nevertheless, this foliage is a very valuable supplementary fodder.

Like *Gmelina, T. grandis* (teak) prefers fertile soils. This tree is not susceptible to lime-induced chlorosis. However, on shallow stony soils with calcic horizons near Oxkutzcab, teak grows slowly, perhaps due to low N and P supplies (1.63% foliar N, 0.13% foliar P) but we cannot exclude that the shallowness of the soil with a field capacity of only 7.2 Vol% is responsible for bad growth. Foliar levels for Mn and Zn are also low (24 ppm Mn, 14 ppm Zn; Table 2, sample 9), but apparently not below the critical range.

No deficiency symptoms were observed on small groups of *Anacardium occidentale* (cashew) growing on red clay soils at the bottom of the slopes. In the mature leaves, only 0.08% P and 0.34% K were found (Table 2, sample 14). This corresponds with our results in West Africa, where cashew reveals P and K deficiencies only when foliar levels are below 0.06% P and 0.30% K, respectively (15, 16).

Table 2. Results of foliar analyses (Oxkutzcab).

Species	No of mixed sample	Description (years old/height) vitality	N	P	K	Ca	Mg	Al	Fe	Mn	Cu	Zn	B
			% (oven-dry weight)					ppm					
Leucaena leucocephala	1	(4/4-6 m) leader dieback, dull green leaves, few small leaves retained	3.87	0.10	1.10	1.96	0.37	53	94	28	8	16	32
	2	(4/1-2 m) severe dieback, few leaves retained, in addition, chlorosis of younger leaves	1.98	0.15	1.39	2.67	0.49	146	98	9	6	19	35
Brosimum alacastrum	3	(3/3-4 m) no deficiency symptoms	2.43	0.15	1.35	2.08	0.48	41	129	29	11	16	24
	4	(2/2.5-3.5 m) no deficiency symptoms	2.27	0.13	1.16	1.93	0.31	22	82	99	6	9	19
	5	(2/2 m) no further symptons	2.30	0.08	1.20	2.45	0.36	21	63	89	10	9	36
	6	(10/6 m) chlorotic leaves, especially in lower parts of the crown	1.44	0.06	0.87	3.20	0.42	21	39	41	6	19	21
Gmelina arborea	7	(3/4 m) intercostal chlorosis, mainly in lower parts of the crown, fertilized with compost	2.91	0.19	0.99	1.65	0.23	99	79	113	19	8	34
	8	(3/4 m) no symptoms	2.50	0.14	0.76	2.20	0.40	68	88	115	17	15	25
Tectona grandis	9	(2/2-3 m) branch growth reduced, only few green leaves retained	1.63	0.13	1.15	1.29	0.13	63	72	24	10	14	30
Manilkara zapota	10	(?/4-5 m) chlorosis of younger leaves, partially only intercostal chlorosis	1.97	0.16	1.96	1.60	0.17	53	27	10	9	17	37
Pinus caribaea	11	(3/2 m) needles completely yellow or short, yellow-tipped needles on the end of the branches	0.83	0.06	1.00	0.46	0.16	58	34	20	2	16	21
Swietenia macrophylla	12	(2/1.5 m) all leaves chlorotic, especially the younger ones	1.00	0.06	0.96	1.61	0.13	51	68	13	13	13	25
	13	(2/1-1.5 m) leaves yellowish-green	1.48	0.08	0.98	2.12	0.13	25	53	37	13	10	30
Anacardium occidentale	14	(?/5-7 m) no deficiency symptoms, growing on red clay soils in bottoms	1.55	0.08	0.34	0.55	0.26	39	53	58	7	16	17

Near **Chetumal**, on shallow Rendzic Leptosols derived from soft marls, many trees develop lime-induced chlorosis. This phenomenon is generally correlated with low foliar Mn. For example *M. zapotilla* ("níspero") growing in the experimental garden of the forest research station shows interveinal chlorosis or even yellowing of the whole leaves. They contain only 10 ppm Mn (Table 2, sample 10). *Manilkara* is most productive near the coast and dislikes clays (3). The wood is suitable for several purposes and the fruit is highly prized and considered one of the best in Central America (3).

On similar sites young *P. caribaea* trees are completely yellow or have short yellow-tipped needles at the end of the branches. These symptoms are probably induced by very low P (0.06%) and Cu (2 ppm) as well as by low N (0.83%) and Mn (20 ppm) foliar concentrations (sample 11).

S. macrophylla, growing near Chetumal, also suffers from N, P and Mn deficiencies. The corresponding foliar levels are 1.00% N, 0.06 - 0.08% P and 13 ppm Mn. Zn levels of 10 ppm may also be insufficient (samples 12, 13).

CONCLUSIONS

These soils are generally difficult substrates for the establishment of most forest trees. High pH reduces availability of nutrients and high stoniness diminishes nutrient reserves and water-holding capacity. Nevertheless, the observed widespread mineral deficiencies are surprising, because most of the trees under study are native to Yucatan and adapted to calcareous soils. This phenomenon might have resulted from environmental changes due to adverse land-use practices. The common form of agriculture is shifting cultivation (milpa) with two to four years of maize followed by forest fallow. Shortened fallow periods have led to incomplete regeneration of soil fertility, especially of the P status of the soils (18), and progressive loss of natural forests has provoked erosion. Such a self- destructive system could have been a reason why the Mayan culture shifted gradually from the center of the Yucatan peninsula towards the ocean (5).

At the beginning of the twentieth century farmers of Oxkutzcab developed the conuco-system, an improved milpa system with smaller fields, multiple cropping and crop rotation. Later they planted fruit-bearing and fodder trees and established permanent systems on parts of their land. Tree gardens such as this are traditionally known as part of Mayan land-use.

The successful management of the cocuno-system is based on careful site evaluation, the avoidance of unsuitable soils and site-adapted species selection. The coexistence of tree garden and crop production prevents financial loss during the first years of tree growth.

As favourable soils for tree or family gardens are now scanty, trees are planted on sites where the foregoing crop production is already declining. The need for integrated strategies is therefore increasing, in view of stable land-use systems based on the experiences of the cocuno-system (10). The aim is to reanimate traditional techniques of ecological land-use, e.g. the production of compost which improves soil fertility and water holding capacity. In Yucatan *Canavalia ensiformis*, intercropped with maize, produced about 1 t of compost/600 m^2. As shown (sample 7), some foliar nutrient levels of compost-fertilized *Gmelina* increased markedly. But as long as commercial fertilizers are not appropriate for smallholder conditions, it will probably be difficult to prevent induced micronutrient deficiencies. On the other hand, these may disappear after canopy closing, as no deficiency symptoms were observed in mature secondary forests nearby with lower topsoil pH.

Communal afforestation programmes should start with site evaluation and tree species trials before establishing large-scale plantations. The use of different species reduces risks of yield damage. Native species should be selected, especially for fodder and fuelwood production. In Yucatan, established plantations of *B. alicastrum* are already producing twice as much forage (three cuttings per year) as pastures (11).

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