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MINERAL DEFICIENCIES IN A PINE PLANTATION IN SOUTHERN ECUADOR

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INTRODUCTION

In many areas of the world pines are often used for afforestation on poor soils, even where this is often not appropriate. Thus the originally very small natural areas of *Pinus radiata* D.Don (Monterey, California) or *Pinus patula* Schl. & Cham. (Central-Mexico) have been expanded considerably by afforestation in the tropics and Mediterranean countries (Kindel 1995, Lavery & Mead 1998).

An afforested slope with *Pinus patula* close to the Andean pass road between Loja and Zamora (Southern-Ecuador, 03°58.0'-58.1'S/79°05.7'-05.9'W, annual precipitation >2000mm) showed distinctly different shape and growth of the trees between sites. The growth of the trees on the east-facing site and on the higher ridge was much lower than on the adjacent lower south-facing site, where taller trees with green needles grew (Fig. 1 A). The lower belt of the south-facing steep slope between 1940 m and 2050 m a.s.l. was covered by 7–17m-high pines with green needles and a dbh (diameter at breast height) of about 10–15 cm. The upper belt of the south facing slope above 2050 m and up to 2250 m a.s.l. and the adjacent eastern slope carried much smaller trees with yellowish, partly necrotic needles, 2–7 m high with a dbh of 2–8 cm (Fig. 1 A–C). The superficial impression of the yellowed needles was reminiscent of a typical European conifer Mg-deficiency, since the whole needles of the older needle generations were yellow or even necrotic, and the younger needles had typical golden tips (Bergmann 1986, 1988). This apparent difference between trees was checked by analysis of needles and soil samples for Mg-, Ca-, K-, and N-content (only needles) to ascertain the kind of deficiency and to develop possible countermeasures.

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METHODS

Locality. *Pinus* plantation on south- and east-facing slopes between 1940 and 2250 m, situated on the eastern slope of the Cordillera El Consuelo in the southern Ecuadorian Andes between Loja and Zamora, above the Biological Station in the Rio San Francisco valley.

Sampling. Needles of all existing needle generations from three different branches were sampled separately, in April 1999, in March 2000, and in November 2000. Samples were taken from new needles, not totally differentiated, from the 2nd, and, if present, from the 3rd and the 4th needle generations, thus up to 4 samples. Soils were sampled from the organic and the mineral horizon separately. Soil samples were air-dried.

Extracts. After drying, the needle samples were thoroughly ground. Dissolution was made by 10% HNO_3 in tightly closed teflon vials at about 160°C, using high interior pressure in the vials for complete dissolution. Soil samples were extracted with 0.1-m-NH_4Cl solution (pH 3) to check the "plant-available fraction" of cation-nutrients.

Analysis. The acid extracts were checked for K, Ca and Mg by atomic absorption (Perkin Elmer 5000) with an acetylene-oxygen flame (Ca, Mg) or with hydrogen-oxygen flame (K). pH was checked by a pH-meter with glass electrode, using the 1-m-KCl extract (ratio 1:2,5); $CaCO_3$ content was checked by the gasometric method according to Scheibler (Steubing 1965). N-analysis was done with thoroughly dry needles using an automatic C-N-S analyzer.

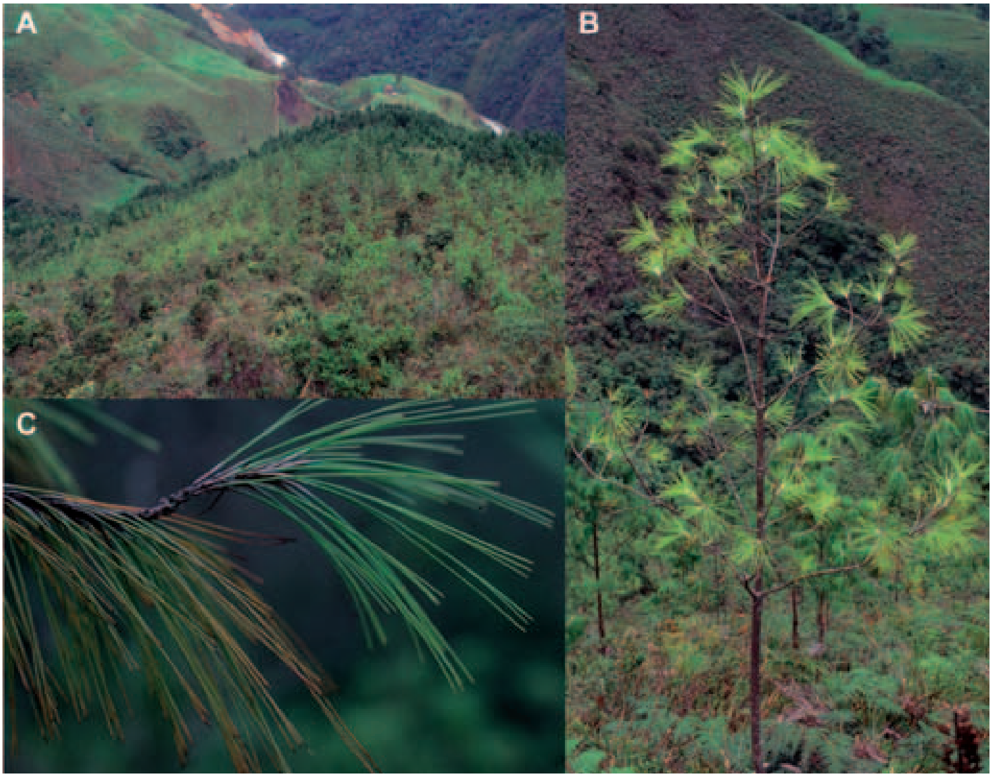

FIG. 1. **A**: Overview of the investigated pine plantation (*Pinus patula*) with taller trees (green belt in the background) on south-facing slope and smaller, yellow-needled pines at higher elevations and on eastern slope. All trees have the same age of 10 to 11 years. **B**: Pine tree from eastern slope with only one generation of yellow needles present. **C**: Two needle generations, youngest looking well, second generation looking yellowish, partly necrotic (phot: A, B: JHo; C: SWBr, all April 1999).

RESULTS

The age of the planted pines is about 10–11 years, according to reports from the village people. Counting the number of branch whorls results in about 19–21. This would mean the pines are producing about two whorls per year, and the similar number of growth rings in the stems are not annual rings; the oldest needle generation would be two years old. The growth of the pines from the lower south-facing slope with green needles is much better than that of the yellowish pines from the upper and the east-facing slope. Their average height is 12.0 m (s.d.: 3.28 m, n = 14), dbh is 19.1 cm (s.d.: 5.6 cm); the yellowish pines were on average 4.57 m tall (s.d.: 1.27m, n = 14) and their dbh was 6.9 cm (s.d.: 4.6 cm). Dbh and tree height is highly significantly correlated (Table 1), indicating an allometric growth pattern, but also significantly correlated are tree size and dbh with exposition and the altitude of tree stands (Table 1, Fig.2).

The pH of the upper soil (1-m-KCl) is on average 2.98 (s.d.: 0.28) at the green pine stands and 2.87 (s.d. 0.23) at the yellowish pine stands. This is not a very significant difference between the two pine stands, and is due to the $CaCO_3$ content, being very low in both soil horizons at both stands (distinctly less than 0.1 % and thus close to the detection limit).

The reduced growth of the yellow-needled pines apparently exhibits typical deficiency symptoms. The question whether these are caused by low magnesium supply or by other factors was revealed by analyses of soils and pine needles.

The analytical data from the mineral soil samples from April 1999 gave no clear result (Fig. 3 A). Soil from the green-needle pine stand had higher values in K, Mg and Ca, on average, but this was not significant because of a wide variation. The mineral soil extracts (Fig. 3 B) from many more soil samples from November 2000 and March 2000 (Fig. 3 C) again showed only slight differences, but in the same direction. Comparing the three sampling dates, all three cations were slightly lower at the yellow-needled pine stand. Soil samples from the upper humus horizon (Fig. 3 D) revealed slight differences between both stands: all cations were lower at the yellow-needled pine stand, though, the standard deviations are very high and thus the statistical significance is rather low. The humus samples had about 10–15 times higher values (mmol per kg dry matter) than the mineral soil (Fig. 3 C, D). Especially for Ca and Mg the difference was considerable.

The green-needle samples from March 2000 from the second year (old needles, Fig. 3 E), however, exhibited the greatest difference in comparison with the yellow needles in their K content (less than half), but Mg and Ca were not significantly different. Ca was very high, demonstrating the accumulation by transpiration water during the past years of physiological activity. This is in contrast to young needles (Fig. 3 F). Ca content in yellow needles is at a lower level even slightly higher than in green needles. The clear difference, however, is with potassium, which in yellow young needles is only half that of green needles. The same pattern is true for the analyzed samples from April 1999 (n = 7), where tree size is clearly correlated with nutrient contents only with potassium content of young needles (Fig. 4 A) and magnesium content of old needles (Fig. 4 B). With Ca there is no correlation.

The physiological role can also be demonstrated by the percentage of cations in young needles in comparison with old needles (Table 2). The changes are considerable. Potassium content of young needles is 50 to 100 % higher than of old needles, while in contrast magnesium is only half and calcium only one third. Despite the fact that the absolute values are very variable, the ratio is rather constant, as is indicated by the relatively low standard deviation (Table 2). The difference between green and yellow needles is, how-

TABLE 1. Correlation coefficients (Spearman's r_s) for growth parameters of *Pinus patula* afforestation.

	dbh	exposition	altitude
tree size	0,949	0,646	– 0,812
dbh	–	0,602	– 0,793

TABLE 2. Means of percentages of cation content in young needles (old needles = 100 %) and standard deviation. Samples from April 1999 (n = 7).

	K	Mg	Ca
green needles	204 ± 75	58 ± 14	31 ± 14
yellow needles	148 ± 33	62 ± 12	36 ± 8

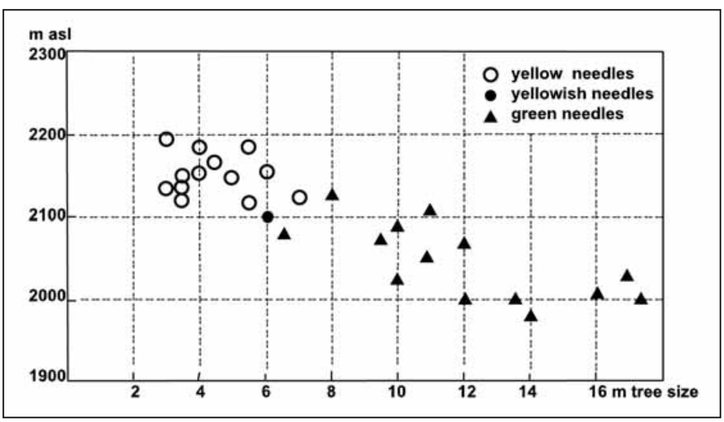

FIG. 2. Tree size decreases with increasing altitude; the needle color of most trees above 2100m a.s.l. is yellow (data from April 1999).

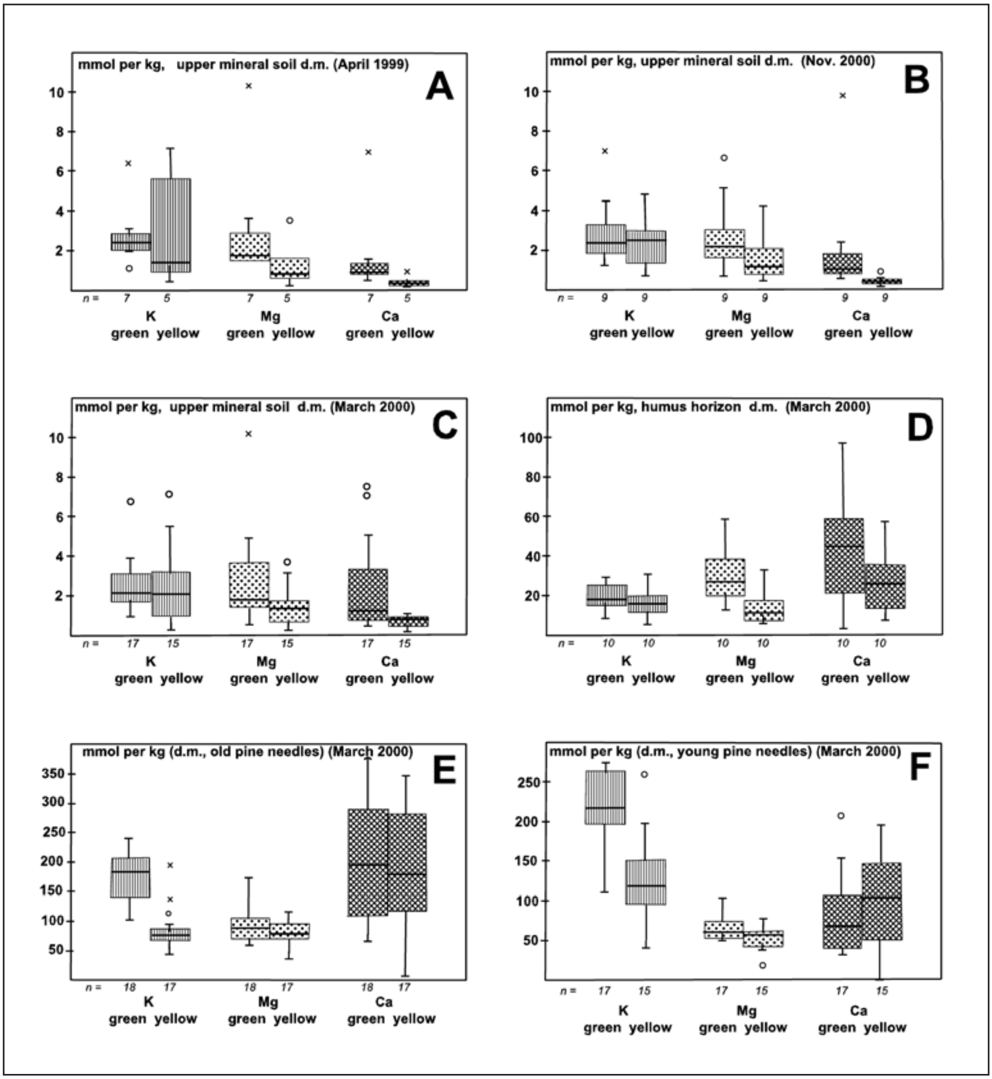

FIG. 3. In all figs. the values from the site with green-needle pines and from the site with yellowish-needle pines are shown using box-plots (with mean value: thick horizontal line, with size of the quartiles, with indicated standard deviation, and with extremes as circles or crosses). Data are given (y-axis) as mmol per kg dry matter (to calculate the formerly used dimensions µg/g = ppm, it is only necessary to multiply the given values by the atomic weight of K, Ca, or Mg respectively); Note the different scaling of y-axes. n = number of samples.

A: Cation content of soil (upper mineral horizon, samples from April 1999; n = 7,

B: Cation content of soil (upper mineral horizon, samples from Nov. 2000; n = 9), some days after a forest-fire.

C: Cation content of soil (upper mineral horizon, samples from March 2000; n = 17; 15)

D: Cation content of soil (humus horizon, samples from March 2000; n = 10)

E: Cation content in one to two-year-old pine needles (samples from March 2000; n = 18; 17)

F: Cation content in young pine needles (samples from March 2000; n = 17; 15)

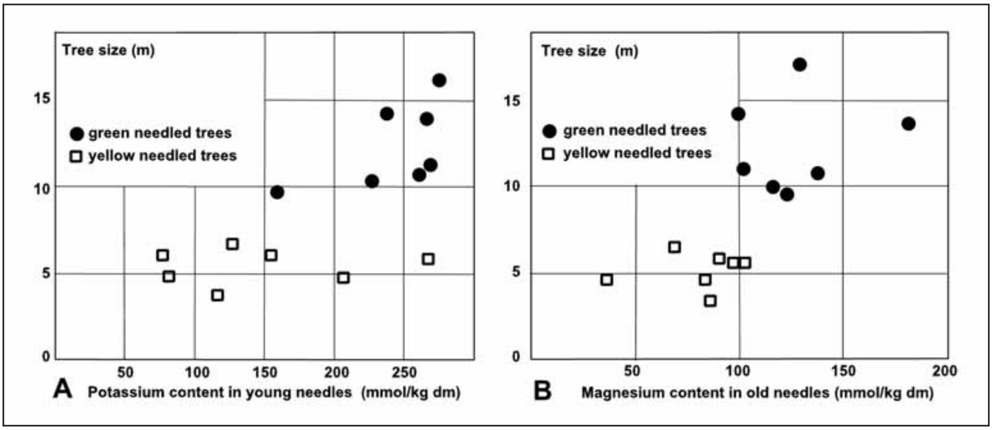

FIG. 4. Tree size is correlated with potassium content in young needles (**A**) and magnesium content in old needles (**B**) from green and yellowed pine tree needles (samples from April 1999).

ever, only significant in potassium, not in magnesium and calcium.

Calculating the statistical significance for all three cations from the other sampling dates there is also no strong correlation of soil and needle values (Table 3). Calculating the probability difference (Table 4) between green and yellow needles and relevant soil samples, there is a rather good p-value (3 %) for Ca values in soil, but not in needles, less for Mg (8–10 %) in soil and needles, and about 11 % in needles but not in soil for potassium.

These are very interesting results, since they show the typical physiological behavior of the cations. Calcium has been passively accumulating in the needles over time by the transpiration of water, but potassium is a very relevant cation for many physiological processes, especially in active young needles. The same is true for Mg, where, however, the soil differences are apparently rather distinctive between the two sites, but the needles exhibit only small differences.

TABLE 3. Correlation Coefficients (Spearman's r_s) for cation contents in soils and needles of *Pinus patula* afforestation (upper number: values from April 1999 samples, lower number: values from March 2000 samples).

	K needle	Mg needle	Ca needle
K soil	0,196 0,263	·	·
Mg soil	·	0,100 0,111	·
Ca soil	·	·	0,105 0,342

TABLE 4: Statistical significance of differences in green- and yellow-needled pine stands. Comparison of concentrations of K, Mg and Ca in soil and needles (1 year old) from April 1999 samples. Results from U-Test.

		K	Mg	Ca
needles	p =	0,116	0,086	0,775
soil	p =	0,57	0,098	0,034*

The total N content in young and old green and yellowed needles was checked in needles from March 2000 (Fig.5). Young needles have a higher N content, and yellowed needles are significantly lower in N content than green needles.

DISCUSSION

The cation values of the soils as well as of the pine needles of the two contrasting pine stands in southern Ecuador do not exhibit a classical single deficiency but apparently a severe multiple mineral deficiency in cations (Zech & Drechsel 1992, Drechsel & Zech

1993). Mineral deficiencies are common in afforestation plantations of the tropics (Zech 1990).

According to Bergmann (1986, 1988), the K deficiency is typically seen with symptoms like yellow needles of the upperparts turning to copper-coloured necrotic needles (red brown tip-scorch). Mg deficiency in conifers is often very pronounced on acid soils, often paralleled by Mn toxicity (Bergmann 1986, 1988). The basal parts of the needles can remain green for some time with Mg deficiency (golden tip-yellowing), but in the Ecuadorian stands most needles of the upper and the eastern slopes were totally yellow or necrotic brown. Slightly deficient intermediate pines exhibited yellow spots between green stripes in older needles, which is known from European conifers to be a Mg deficiency symptom.

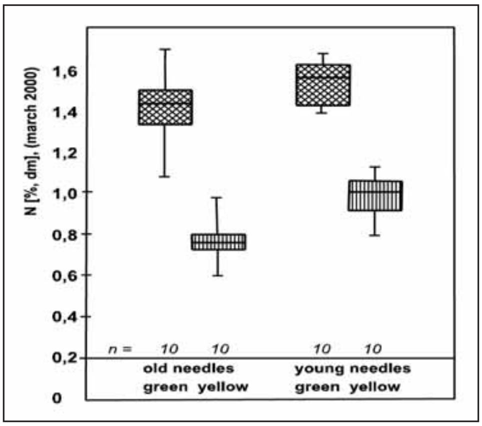

FIG. 5. N content of old and young, yellow and green needles (samples from March 2000).

Ca deficiency produces no clear symptoms in needles except a reduced growth, but it is known from many sites and experiments that root growth is severely inhibited (Bergmann 1988, Marschner 1986). This causes an overall limitation of growth and indirect effects on the physiology of the other cations, mainly K.

N deficiency is normally not recorded from conifers since they have an efficient mycorrhiza and are adapted to a low N supply. N deficiency in conifers is normally characterized by a brightening of the normally dark green needles. In most industrial countries, forests have an additional N supply by exhausts from traffic etc., which can even cause ecological problems and instability of trees (Waldzustandsbericht Bayern 2003). The N dynamics of forests is very complicated and a clarification would need several analytic procedures (Marschner 1986) and incubation experiments with soil samples. It is very unlikely that in the Ecuadorian pine plantation N deficiency is the main reason for the yellowing appearance and reduced growth. The distinctly lower N-content in yellowed needles (Fig. 5) has to be interpreted as a secondary sign of a disturbed overall physiology caused by cation deficiency and N remobilization.

It seems obvious that the yellowish pines are subject to a multiple cation deficiency. This could be caused by multiple burning practices with loss of the minerals by strong leaching from the ash under the tropical rain regime. According to reports from the local people, those areas had been burned several times, then used for grazing before they were afforested with the exotic pines. The mineralization of pine needles is slow in contrast to the litter of the natural forests. Thus internal mineral cycling (Bellot *et al.* 1999, Wilcke *et al.* 2001), which is the main supply of cation nutrients in tropical forests, is inhibited in pine plantations. The internal short-cut of nutrient cycling is interrupted (Walter & Breckle 1984, 2004). Additionally, the water-budget is drastically altered with increased throughflow (Bellot *et al.* 1999, Meinzer *et al.* 2001, Wilcke *et al.* 2001). The green-needled pine stand has slightly better soil conditions and with increasing altitude there is often a soil gradient of impoverishment in nutrient cations (Schrumpf *et al.* 2001), but it is not yet clear if the reasons are geologic or anthropogenic, (e.g.) a differing former burning regime in the upper forestry parts.

It was reported by Chapela *et al.* (2001) that ectomycorrhizal fungi, introduced with exotic pine plantations, can cause impoverishment of the carbon pool and thus of the essential cations in soils. If areas have been frequently burned, which is the case in this mountain-belt in Ecuador, the soils become very poor in nutrients by rapid leaching of the ash under the tropical, very wet climate.

In conclusion it should be stated that forestry under those conditions, with impoverished soils and steep slopes, is never economic. The necessity to fertilize those huge slopes for an uncertain afforestation would be extremely high, especially under the regime of strong tropical rains. The only suggestion for rehabilitation can be to find some native tree species from the close vicinity and to try to create initial stands for further extension in future. There is an urgent need to minimize the very high danger of erosion and even landslides. It will need labor-intensive work and maintenance to overcome the bracken invasion (*Pteridium aquilinum*) (Hartig & Beck 2003) or the outshading competition by the high, aggressive introduced grasses, like *Setaria sphacelata* or *Melinis minutiflora*. This is probably best achieved by a two-phase afforestation, starting with fast growing pioneer trees intermixed with native late-successional species from the adjacent natural forests.

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