Soil fertility of *Pinus taeda* L. areas with low growth rates in Jaguariaíva – Paraná State, Brazil

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Abstract
Pine forests in Brazil have reached a high level of productivity. However, there are many areas with low rate of plant growth, associated with low soil fertility. Seven sites showing low rate of plant growth were selected and sampled for soil and litter analysis, in order to establish the limiting factor of soil fertility. Soils samples were collected within the following depths (0-20, 20-40 and 40-60 cm) and analyzed for soil fertility properties. Total soil concentration of K was also determined. Litter accumulation and its nutrient concentrations were established for each site. The results indicated that the soils were very acid with Al saturation higher than 75%, for all samples. Ca, Mg and K availability varied from < 0.1 to 0.4 < 0.1 to 0.2 $cmol_c$ /dm^3, and 2.5 to 21.5 mg/dm^3, respectively. The total concentration of K varied from 97 to 360 mg/kg of K, indicating a very low level of K reserves. The litter accumulated on the soil surface showed the influence of plant age and insufficient decomposition, forming a typical moder profile. The data suggested that lime and nutrient applications may be necessary to promote plant growth.

Key words
Pinus taeda, forest soil, soil acidity, soil nutrients reservoir, Cerrado, Brazil.

Introduction
During the 60´s the Brazilian government promoted a large reforestation program in the south. Pine species were selected reflecting the favorable subtropical climate condition and the original low soil fertility. Today, the pine reforestation is concentrated in the three southern states, where in Paraná the covering area reaches 686,453 ha (ABRAF 2007).
The good plant adaptability has been shown by the high productivity (Higa and Silva 2008). Depending on site quality, this productivity varies from 15 to 56 /m^3/ha/y (Mainarde *et al*. 1996). Despite the low fertility requirement, there are indications that nutritional lack has been limitimg pinus growth under some conditions (Chaves and Corrêa 2003; 2005). This fact has been observed in reforestations occupying earlier Cerrado vegetation areas, which are well known to have very low soil fertility.
Fertilizer application is not usual practice in pine plantations so nutrient depletion exacerbated by log extraction without nutrients return can start to impact on plant growth on poor soils after the second cut cycle.
Soil chemical and plant tissue analysis are the most used tools to evaluate the abundance of nutrients or toxic elements which can compromise plant growth (Reissmann 1981). These tools have been shown to be effective to distinguish different growth sites in the Brazilian pinus plantation (Wisniewski and Reissmann 1996; Vogel 2003). However, there were conditions where these tools had low efficiency like in Cerrado soil (Chaves and Corrêa 2003; 2005) where soils are very likely to have more than one limiting factor.
Litter accumulation on forest floor and its quality can also be used to evaluate pine growth sites (Mead 1984). For the same age plantation, an inverse relationship was observed between litter accumulation and plant growth (Wisniewski and Reissmann 1996).
Located in the north of Paraná State, Jaguariaiva region is the transition area between subtropical and tropical climate condition. The regional natural vegetation reflects this climate transition where subtropical forest of araucária, subtropical grassland and Cerrado (Brazilian savanna) share the soil occupation. Also, two kinds of sandstone are the major parent materials forming soils, giving a sandy texture to the soils as well as low nutrient reserves. The region has lower pinus growth rates compared to others region and responded to nutrient applications as organic residue (Rodrigues 2005). Our objective was to collect and analyze soil and litter in order to identify factor limiting plant growth.

Material e methods
Commercial pinus plots plantations were selected, near Jaguariaíva city. The region is located on the second

paranaense high plain, with altitudes between 960 to 1320 m. Furnas and Itararé sandstone are the soil parent material for the region. The regional climate is a transition between subtropical and tropical, with mean annual precipitation ranging from 1440 to 1600 mm and mean temperature from 17 to 19ºC. Frost occurs almost every year.
Using a 50000 ha inventory, it was selected seven sites. Five of them had age 4 and 5, one 11 and one 17 years old. The plantation was made 2 x 3m spacing and all was at least one time cropped with pinus or eucalyptus. For each plot it was selected an area of 1.2 ha (96 x 112 m), representing 34 lines. Then, it area was split in four line of 8 lines where it was collected eight soil samples within 0-20, 20-40 and 40-60 cm depth, in order to form one compost sample for each depth.

In the same places where were collected the soil samples were collected the litter (L, F and H) horizon. After dry at 60 ºC, the litter samples were weighted, ground using Wiley type. Then samples were submitted a dry combustion (500 ºC) and attack with HCl 3 mol/L, and analyzed for macro and micronutrients according with Martins and Reissmann (2007).

Soil samples were dried, sieved and analyzed for pH ($CaCl_2$ 0,01M – 1/2.5 soil/solution), Al toxic (extractable Al – KCl 1 M), $H^+ + Al^{+3}$ (buffer capacity until pH 7,0), available Ca and Mg (extractable KCl 1 M), available K and P (Mehlich I extraction) and total organic Carbon (C) (Walkley-Black methods), following Marques and Motta (2003). Total, non exchangeable, and exchangeable K were determined by using concentrated HF, boiling HNO_3 1N, and ammonium acetate 1 mol/L, respectively. (MELO, 1994)

Results and discussion

Soil Fertility

Soil results (Table 1) indicated that the soil were very acid high with low pH, high exchangeable Al and saturation. It was expected since the soil was natural acid and not lime was applied on pinus plantation. High values of (H + Al) can be associated with low pH and high organic C, and indicated high buffer capacity. Following the high soil acidity, very low level of Ca and Mg was observed, suggesting possibility of deficiency. Application of lime as Ca and Mg source is recommended, especially because there are large lime reservoirs close and price was accessible.

Table 1. Mean values of pH, Al, (H + Al), m % (Al saturation), C (total organic carbon), Ca, Mg, and P (Mehlich I), for seven soils under pinus in the Jaguariaiva region – Brazil.

	pH			Al^{+3}			$(H^+ + Al^{+3})$			m (%)		
	1*	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
						$cmol_c/dm^3$					%	
P1	3,8	4,1	4,1	2,7	1,7	1,6	10,9	7,9	7,1	81	81	81
P2	4,0	4,2	4,2	1,5	1,2	1,1	6,5	5,2	4,7	81	76	77
P3	4,1	4,1	4,2	1,6	1,3	1,0	9,4	8,4	7,8	78	75	76
P4	3,9	4,1	4,1	1,9	1,4	1,2	8,0	5,8	5,5	85	80	82
P5	3,9	4,0	4,1	1,3	0,9	0,8	6,5	5,5	5,3	84	77	75
P6	4,0	4,1	4,1	1,5	1,1	0,9	7,2	6,0	5,9	85	84	81
P7	4,0	4,1	4,1	1,6	1,3	1,2	8,5	8,1	7,8	84	84	85
	C			**Ca**			**Mg**			**P**		
	g/dm^3			$cmol_c/dm^3$						mg/dm^3		
P1	29,9	24,5	18,0	0,4	0,3	0,3	0,2	0,1	0,1	6,4	3,2	1,9
P2	25,0	17,8	17,2	0,3	0,3	0,2	0,1	0,1	0,1	2,9	1,0	0,4
P3	33,6	24,0	19,7	0,3	0,2	0,2	0,2	0,1	0,1	2,6	0,4	0,4
P4	18,2	16,3	12,0	0,2	0,2	0,2	0,1	0,1	0,1	2,3	1,0	0,4
P5	17,7	13,8	13,9	0,2	0,1	0,2	0,1	0,0	0,1	0,4	0,2	0,1
P6	20,3	15,3	13,0	0,2	0,1	0,1	0,1	0,0	0,1	0,7	0,6	0,2
P7	24,9	16,3	13,4	0,2	0,1	0,1	0,1	0,0	0,0	0,5	0,1	0,2

*1 – 0-20 cm depth; 2 – 20-40 cm depth; 4-60 cm depth.

The same was observed for available K (Mehlich I) as well as total and non exchangeable (HNO_3) (Table 2). The level of K total obtained was bellow to others in the south (Martins *et al.*. 2004, Nachtigalll and Vahl 1989 and Melo 1994) but similar to observed to Cerrado region (Ritchey 1982). Since the non exchangeable K has been considered a medium and long term reservoir farmer cannot afford to have this reservoir to supply K for these soil types. This suggests that K can be a limiting factor to pinus growth, fertilizer application need to be test. Phosphorus can also be problem since low and very low levels were obtained (Payn *et al.*. 1988).

Table 2. Mean values (mg/kg) of total, non-exchangeable (HNO_3), Mehlich I, and exchangeable K (ammonium acetate) for seven soil under pinus in the Jaguariaiva region – Brazil.

	Total			HNO_3			Mehlich I			Ammonium acetate		
	1*	2	3	1	2	3	1	2	3	1	2	3
P1	117	138	147	33,0	24,3	25,5	20,5	12,7	10,7	14,8	9,3	5,5
P2	250	357	357	30,5	23,0	24,0	14,6	7,8	7,8	12,0	4,5	3,3
P3	197	196	192	39,5	28,0	21,5	21,5	13,7	12,7	21,5	10,8	5,5
P4	319	315	360	31,5	25,3	26,5	12,7	8,8	5,9	9,3	4,8	2,5
P5	98	103	107	13,8	10,5	9,8	12,7	7,8	7,8	8,0	3,3	4,3
P6	168	213	192	18,0	14,8	11,5	10,7	5,9	5,9	8,3	4,3	4,3
P7	109	164	97	25,0	19,0	15,5	16,6	11,7	7,8	17,0	10,3	6,8

*1 – 0-20 cm depth; 2 – 20-40 cm depth; 4-60 cm depth.

Litter and nutrients

The amount of litter on Forest floor was affected by forest age with the plantations with 11 and 17 high values (Table 3). However, the age could not explain the high values observed site number 7. This fact could be related with soil fertility, but it was not possible to confirm give the influence of first plantation.

The carbon concentration did not vary among sites so the amount of C retained on litter was direct related with total litter mass (Table 3). Very low concentration of P, K, Zn and Cu observed (Table 3) in our study indicated that the amount of nutrients on litter is small. Also, this fact can be result of low nutrients availability or leaching process (mobile elements). In opposite way, high level of Fe and Mn obtained can be result of very low soil pH. Theses fact can be also give by Zn deficiency which is very common under Cerrado condition.

Table 3. Mean values for macro and micronutrients in litter for seven sites under pinus in the Jaguariaiva region – Brazil.

Sites	Age	Litter	C	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	years	kg/ha	g/kg						mg/kg			
1	5	3404	472	6,7	0,77	0,50	3,44	0,80	297	605	6,9	4,48
2	5	4347	465	7,1	0,73	0,55	2,64	0,91	437	177	3,6	3,26
3	5	3541	473	7,6	0,67	0,70	3,49	0,70	419	416	10,9	4,16
4	11	24656	470	10,5	0,73	0,45	0,80	0,11	526	107	4,5	4,17
5	5	4093	479	8,0	0,58	0,56	0,80	0,76	422	1107	6,6	1,33
6	17	13069	472	12,2	0,95	0,51	0,79	0,23	979	76	1,4	1,55
7	5	16240	459	12,4	0,96	0,49	0,59	0,25	1075	78	1,2	1,73

Conclusions

Soil from Jaguariaiva region showed to be very acid, with low nutrients availability and K reserve. The litter showed to be very poor and also may not contribute to supply plant growth. Lime and fertilizer application may be necessary to reach similar yield from others states regions.

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