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Effects of red-yellow soil acidification on seed germination of Chinese pine

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Abstract: Acid treatments significantly change the physical and chemical properties of red-yellow soil by lowering its pH value and leaching out aluminum(Al) ions that are harmful to the growth of plants. The structure of soil will be damaged, resulting in higher viscosity, higher water retention rate and lower air permeability of the soil. The germination rate of Chinese pine(*Pinus tabulacformic Carr.*) seeds sowed in soil treated with sulphuric acid(H_2SO_4) decreased compared to that for untreated soil. The direct cause was the large amount of Al ions leached out because of low pH values($\geqslant 3.5$). The added acid decreased the soil aggregation and increased the number of micro-aggregates(under 250 μm in diameter). Such changes increased the soil's viscosity, which tied the pine needles to the soil after the seeds had germinated and prevented the seedlings from fully developing.

Keywords: aluminum ion; germination of Chinese pine; red-yellow soil; soil aggregates; soil viscosity

Introduction

Since the end of 1970s, acid deposition has caused the decline of large patches of forest in many areas of southwest China(Liu, 1989; Ma, 1989). An investigation in Mao County, Sichuan in the second half of 1996 found a large of number of dead Chinese pines(*Pinus tabulacformic Carr.*) in association with acid deposition. Though the causes of the forest decline may be complex, acid deposition is a plausible and potentially important contributor. This highlights the necessity for systematic research on the impact of acid pollution on the growth of the Chinese pine. Xiang(Xiang, 1989) suggested that acid deposition can not only affect the growth of trees directly, but may also play a role indirectly by acidifying the soil in which the trees grow. Therefore, the impact of soil acidification on the growth of the Chinese pine should be a component in the research of the overall effects of acid deposition. This research was designed to provide further insights into this matter.

1 Materials and methods

The soil used was red-yellow soil from the Experimental Farm of Aichi County, Japan. The soil from the upper 40 cm was passed through a 5 mm sieve.

The treatments I, II and III were added 30 meq, 60 meq and 90 meq H^+/L soil, 100 ml of 0.6 mol/L, 1.2 mol/L and 1.8 mol/L sulphuric acid(H_2SO_4) solutions per litre soil, respectively. After three days, the soil in the three treatments and that in the control were mixed with 3L ion-free water. The water was drained after another week and the four types of soil were moved to 500 ml polyethylene pots.

Each treated group consisted of 20 pots, each of which contained 15 seeds. The pots were then sprayed daily with ion-free water.

Germination of pine seeds under different pH values: Pine seeds were placed in Petri dishes padded with filter paper, which was then soaked daily with H_2SO_4 solutions at pH 3.0, 3.5, 4.0 and 5.6 (control). Each of the above treatments consisted of ten Petri dishes, each of which held 30 seeds.

Germination of pine seeds under different concentrations of aluminum ion: Pine seeds were placed in Petri dishes padded with filter paper, which was then soaked daily with aluminum ion solutions at 0 mg/L (control), 10 mg/L, 30 mg/L, 50 mg/L and 70 mg/L in concentration. All the solutions were adjusted to pH 4.0 with H_2SO_4. Each of the above treatments consisted of ten Petri dishes, each of which held 30 seeds.

Analysis of soil aggregates used R.E.Yoder method(Liu, 1982).

Analyses of chemical elements of soil: Ten grams soil after treated was mixed with 50 ml of ion-free water. The mixture was shaken continuously for 60 minutes and filtered with filter paper. The concentrations of calcium(Ca), magnesium(Mg), potassium(K), Al and manganese(Mn) in the filtrate were analyzed with an atomic absorption spectrometer(model AA-670/GV6) manufactured by SHIMADZS, Inc. of Japan.

The above experiments were conducted at Tokyo University of Agriculture and Technologies, Japan, between April 1 and August 31, 1997.

2 Results

2.1 pH values and ion concentrations of soil solutions

The pH values of the solutions of the soil within the pots decreased as the concentrations of H_2SO_4 with which the soil was treated increased(Table 1). In treatments I, II and III, the soil solution pH value decreased by 0.77, 1.16 and 1.27, respectively, compared to that of the untreated soil. Aluminum and manganese ion concentrations increased with decreased pH values. In treatments I, II and III, the Mn ion concentrations were 18.5, 27.5 and 28 times, respectively, that for untreated soil. The Al ion concentrations were 17.2, 163 and 448 times, respectively, that for untreated soil, displaying a significant negative correlation with the pH values. The K, Ca and Mg concentrations also increased with the decreased pH values, although not as dramatically as the Al concentrations. In addition, the concentrations of these three elements were at the same order of magnitude.

Table 1 Ion concentration(mg/L) and pH of soil solution analysis conducted just before sowing the Chinese pine seeds to the potted red-yellow soil

	pH		Ion, mg/L				
	H_2O	KCl	Ca^{2+}	Mg^{2+}	K^+	Mn^{2+}	Al^{3+}
Control	4.93	3.79	0.31	0.20	0.66	0.51	0.16
	(0.00)	(0.00)	(0.01)	(0.01)	(0.04)	(0.03)	(0.01)
Treatment	4.16	3.57	1.15	1.00	1.63	9.44	2.75
I	(0.02)	(0.01)	(0.08)	(0.02)	(0.07)	(0.47)	(0.13)
Treatment	3.77	3.51	1.67	1.69	2.48	14.0	26.0
II	(0.01)	(0.01)	(0.10)	(0.09)	(0.11)	(0.92)	(1.55)
Treatment	3.66	3.46	1.93	2.93	2.16	14.3	71.8
III	(0.01)	(0.01)	(0.14)	(0.20)	(0.18)	(0.61)	(3.48)

Note: each value is the mean of 4 determination. Values in parentheses show standard deviation.

2.2 Analysis of water stability of soil aggregates and volumes different components of the soil

Less acid-treated soil remained on the sieves of various mesh numbers than untreated soil. In other words, larger portions of the soil passed through the sieves when the soil had been treated with more concentrated H_2SO_4(Table 2). The smaller the screen size, the lower the pH value of the soil solution, the larger the difference. At a screen size of 0.5 mm, penetration rates for the soil in treatments I, II and III were 132%, 144% and 148%, respectively, that for untreated soil. At 0.3 mm, the respective ratios were 118%, 157% and 161%. At 0.1 mm, the respective ratios were 114%, 160% and 200%. This suggests that soil acidification can disintegrate large soil aggregates; the diameters of soil aggregates decrease as pH value of soil solution decreases.

Table 2 Analysis of water-stable aggregates of red-yellow soil conducted just before sowing the Chinese pine seeds

	Sieve, mm	RR, %	RAR, %	PTAR, %	PTAR/PTARC
Control	2.0	14.4(0.8)	14.4	85.6	
	1.0	18.3(0.7)	32.6	67.4	
	0.5	21.8(1.3)	54.4	45.6	
	0.3	15.2(0.8)	69.6	30.4	
	0.1	12.1(0.4)	81.8	18.4	
Treatment I	2.0	10.2(0.8)	10.2	89.8	105
	1.0	12.0(0.6)	22.2	77.8	115
	0.5	17.5(1.5)	39.7	60.3	132
	0.3	24.3(1.7)	64.0	36.0	118
	0.1	15.0(1.1)	79.0	21.0	114
Treatment II	2.0	11.5(0.6)	11.5	88.5	103
	1.0	9.7(0.7)	21.2	78.8	117
	0.5	13.3(0.8)	34.5	65.5	144
	0.3	17.7(1.2)	52.2	47.8	157
	0.1	18.4(1.1)	70.6	29.4	160
Treatment III	2.0	6.8(0.4)	6.8	93.2	109
	1.0	10.9(0.9)	17.7	82.3	122
	0.5	14.8(1.1)	32.6	67.5	148
	0.3	18.6(1.4)	51.0	49.0	161
	0.1	12.1(0.8)	63.1	36.9	200

RR: remain ratio; RAR: remain accumulation ratio; PTAR: pass through accumulation ratio; PTAR/PTARC: PTAR/PTAR of control. Each value is the mean of 3 determination. Values in parentheses show standard deviation

Volumes of soil solids, water and pores in the red-yellow soil changed significantly after the soil was treated with acid(Table 3). Compared to those in the untreated soil, the volumes of air(pores) in the soil in treatments I, II and III decreased by 57%, 66% and 75%, the volumes of water increased by 65%, 70% and 75%, and volumes of soil solids increased by 16%, 24% and 31%, respectively. These results show that, for soil columns of a given size, space occupied by air decreases and those occupied by water and soil solids increase as the pH value of soil solution decreases. In other words, acid-treated soil has better water retention ability but is more poorly aerated.

Table 3 Result of three phases of red-yellow soil analysis conducted just before sowing the Chinese pine seeds in the soil(%)

	Control	Treatment I	Treatment II	Treatment III
Gas phase volume	40.3(3.5)	17.4(1.2)	13.7(0.9)	10.0(0.7)
Liquid phase volume	26.9(2.2)	44.5(1.8)	15.6(2.5)	47.0(1.9))
Solid phase volume	32.8(2.8)	38.1(2.1)	40.7(2.2)	43.0(2.6)

Note: each value is the mean of 3 determination. Values in parentheses show standard deviation

2.3 Germination of pine seeds

Seeds in treatment I had a slightly higher germination rate than those in the untreated group(Table 4). However, in treatment II the rate was much lower; and in treatment III, it approached zero. Table 5 gives germination data of the treatment II seeds. Some seeds germinated normally and developed into healthy seedlings. Others, however, after the stems broke through the soil, had their needles stuck in the soil, which had been made more viscous by the acidification. With the plants' needles bound to the ground, tension created by the growth broke some of the plants' bent stems while uprooting other plants.

As a result, the seedlings died. In still other cases, the seeds did not germinate at all.

Table 4 Germination of Chinese pine seeds sowed in red-yellow soil treated with H_2SO_4 solution

	Control	Treatment I	Treatment II	Treatment III
Germination amount/Pot	7.1	7.6	3.4*	0.05**
Germination ratio, %	47.3	50.7	22.7	0.3

* $P<0.05$; ** $P<0.01$

Table 5 Germination status of Chinese pine seeds sowed in the soil of treatment II

	Germination	Stand upside down	Stem broken	Non-germination
Total amount	67	8	19	206
Percentage, %	22.3	2.7	6.3	68.7

In Table 6, germination rate decreased slightly when Al concentration reached 10 mg/L. At Al concentrations of 30 mg/L and 50 mg/L, germination rates were 67.8% and 63.5% of that of the untreated group, respectively. At 70 mg/L, some seeds broke the seed skin but did not grow seedlings. Therefore, Chinese pine can germinate when Al in the soil is below 50 mg/L, although germination rate will decrease.

Table 6 Germination of Chinese pine seeds with different concentration of Al ion

	0 mg/L	10 mg/L	30 mg/L	50 mg/L	70 mg/L
Amount/Pot	11.5	11	7.8	7.3*	0**
Percentage, %	38.3	36.7	26.1	24.2	0

* $P<0.05$; ** $P<0.01$

In Table 7, seeds in the pH 4.0 treatment had the highest germination rate, 129% of that of the untreated seeds. At pH 3.5, the germination rate was 108% of that of the untreated seeds. At pH 3.0, the germination rate decreased to 42% of that of the untreated seeds, but germination did take place.

Table 7 Germination of Chinese pine seeds with different pH

	PH 5.6	pH 4.0	pH 3.5	pH 3.0
Amount/Pot	9.5	12.3	10.3	5.5*
Percentage, %	31.7	40.8	34.2	18.3

* $P<0.05$

3 Discussion

The soil aggregate structure is constructed of macro soil aggregates, which are in turn constructed of micro soil aggregates. Edwards and Bremner(Edwards, 1967) and Tisdall and Oades(Tisdall, 1982) point out that the threshold between macro- and micro-aggregates is 250 μm, i.e., those with diameters larger than 250 μm are considered macro-aggregates, and those with diameters smaller than 250 μm micro-aggregates. They further note that soil waters around macro- and micro-aggregates have different compositions, making the latter more viscous than the former. Therefore, a higher portion of small soil aggregates means more viscous soil. In this research, soil aggregates passing through the 100 μm sieve were by definition micro-aggregates. This kind of aggregates was 160% and 200% in treatments II and III compared to the untreated sample, and may explain the higher soil viscosity in the two treatments. But the report of the relationship between soil viscosity and germination of Chinese pine seeds was not seen.

Acid treatments in combination with soaking in water alter the structure and physical properties of soil aggregates. Soil aggregates disintegrated by water coagulate when the water evaporates, forming a hard "shell" on the soil surface almost impermeable to water and air and impenetrable to the seedlings(Xu, 1993). This is what happened in treatments II and III. The decrease in the soil aggregate sizes also resulted in the change in the volumes of the three components. In the soil samples from these two treatments, volumes occupied by air were only 34% and 25% of that of the untreated soil sample. The existence of the shell prevented an external supply of air, which the seeds needed for respiration. Therefore, too little air in the soil is a likely reason for the low germination rates.

Miwa *et al*. (Miwa, 1994) and Lee *et al*. (Lee, 1997) reported only small amounts of Al ions being leached out when solution pH value is above 4.0. When the pH value drops below 4.0, large amounts of Al ions are leached out, as was observed in this research. High concentrations of soluble Al can be toxic to plants, resulting in retarded growth and even death (Miwa, 1994; Lee, 1997; Izuta, 1996). In this research, germination rate started declining when Al concentration was 30 mg/L. When Al concentration reached 50 mg/L, germination rate was only 63.5% of that of the untreated seeds. When it reached 70 mg/L, no germination took place. According to Lee (Lee, 1997), Mn and Al both have adverse effects on plants, but Al is more toxic. In this research, the Al ion concentration was three times in treatment III as in treatment II, whereas the Mn ion concentrations were similar in both treatments. The fact that seeds were able to germinate in treatment II but barely in treatment III clear indicates the effects of Al ions. Mn, on the other hand, played a minor role because of its low concentrations.

The results in Table 7 showed that the decrease in pH value alone did not cause a decrease in the germination rate. This demonstrates that the low germination rates were not a direct result of the low pH values in the acidified red-yellow soil, but rather a result of the increased soil Al ion concentrations caused by the low pH values.

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