EFFECTS OF SHORT-TERM EXPOSURE OF SIMULATED ACID RAIN ON THE GROWTH OF *ACACIA NILOTICA*

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Received May 2006

BALASUBRAMANIAN, G., UDAYASOORIAN, C. & PRABU, P. C. 2007. Effects of short-term exposure of simulated acid rain on the growth of *Acacia nilotica*. The response and measurable effects of simulated acid rain at different pH levels of 3.5, 4.5, 5.5, 6.5 and 7.0 on *Acacia nilotica* seedlings grown on black and red soils were investigated for six months. A set of 10 potted seedlings in each treatment was exposed to 15 min foliar spray of 125 ml simulated rain acidified with sulphuric and nitric acids at a ratio of 2:1. The simulated rain was sprayed in 10 spells from 45–70 days after planting. The study was conducted in the non-monsoon season to exclude ambient rain. Increasing acidity of simulated acid rain resulted in a general decrease in all growth characters of seedlings in both soils, namely, plant height, root length, leaf number, total dry matter accumulation, leaf dry weight, stem dry weight, root dry weight, leaf area, single leaf size, specific leaf area, leaf area index, leaf area ratio and crop growth rate. However, *A. nilotica* on red soil showed deleterious morphological and growth characters when exposed to simulated rain at pH 3.5 compared with those on black soil.

Keywords**:** Red soil, black soil, growth characters, acidity, foliar application

BALASUBRAMANIAN, G., UDAYASOORIAN, C. & PRABU, P. C. 2007. Kesan jangka pendek simulasi hujan asid terhadap pertumbuhan *Acacia nilotica*. Tindak balas serta kesan yang boleh diukur bagi simulasi hujan asid pada nilai pH 3.5, 4.5, 5.5, 6.5 dan 7.0 terhadap anak benih *Acacia nilotica* dikaji selama enam bulan. Anak benih itu ditanam dalam tanih hitam dan merah. Sebanyak 10 pasu anak benih bagi setiap rawatan simulasi didedahkan selama 15 minit kepada semburan dedaun yang mengandungi 125 ml hujan asid tiruan. Nilai pH hujan asid tiruan itu ditetapkan dengan menambah campuran asid sulfurik dan asid nitrik dalam nisbah 2:1. Semburan hujan asid tiruan dibuat sebanyak 10 kali bermula dari 45 hari selepas penanaman hingga 70 hari. Kajian dijalankan di luar musim monsun untuk mengelakkan hujan asli. Secara amnya, pertambahan keasidan hujan asid tiruan menyebabkan pengurangan ciri pertumbuhan anak benih dalam kedua-dua jenis tanih. Ini termasuk ketinggian pokok, panjang akar, jumlah daun, jumlah pengumpulan bahan kering, berat kering daun, berat kering batang, berat kering akar, luas daun, saiz daun tunggal, luas spesifik daun, indeks luas daun, nisbah luas daun dan kadar pertumbuhan pokok. Bagaimanapun, *A. nilotica* dalam tanih merah menunjukkan kesan morfologi serta ciri pertumbuhan yang teruk apabila didedahkan kepada hujan asid tiruan yang mempunyai pH 3.5 berbanding anak benih dalam tanih hitam.

INTRODUCTION

Acid rain (pH < 5.6) is currently regarded as one of the most widespread and environmentally significant consequence of atmospheric pollution, rapid industrialization, urbanization and development. The acidity of rain in many parts of the world has increased over the past years and this phenomenon has been linked primarily to increased emissions of oxides of sulphur and nitrogen from the combustion of fossil fuels.

Fossil fuels account for about 80% of energy consumption in Asia. Due to its abundance and easy recoverability, especially in India and China, coal will remain the fuel of choice in the foreseeable future. In Asia, sulphur dioxide emissions are projected to triple from a level of 34 million tonnes in 1990 to a worst case scenario of about 110 million tonnes by 2020 if no control measures are taken (Downing *et al.* 1997). Oxides of nitrogen emissions are projected to more than quadruple over the same period from 19 to 86 million tonnes (van Aardenne *et al.*1999). These increases are driven by the rapid growth of Asian economics, the inefficiency of energy use, the

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reliance on coal as major energy supply and the rapid increase in the number of vehicles.

The production of SO_2 emission in India is the second highest in the Asian continent, next to China. Acid rain in India tends to be a local phenomenon near major industrial areas. Integrated analysis using the RAINS-ASIA (Regional Air Pollution Information and Simulation Model for Asia) model showed that wet and dry depositions in Agra, India were at rates of 161.1, 49.9 and 176.8 eq. ha^{-1} per year respectively for sulphur, nitrogen and ammonium (Bhattacharya *et al.* 2003).

When the environment cannot neutralize acids deposited or soils contain insufficient alkali to neutralize acid inputs damage can be caused to vegetation particularly to sensitive tree species and agricultural crops. One of the most serious impacts of acid rain is soil acidification that leads to several changes in the rhizosphere environment including increased leakage of essential nutrients and increased concentration and activity of potentially toxic metals such as Al in the soil solution. Excess Al makes root hairs unable to take up sufficient water and essential plant nutrients such as Ca and Mg resulting in poor performance and starvation of plants (Totsuka 1994).

Foliar applications of simulated acid rain have been reported to result in significant reductions in soybean yield and quality under experimental field conditions using standard agronomic practices (Evans *et al.* 1981). In another study, however, simulated acid rain of pH 5.3 and 3.1 did not affect the grain development in soybean at flowering and pod-filling stages (Irving 1983). In contrast, an increased soybean and alfalfa yield due to exposure of acid rain was reported by Lee *et al.* (1981). Simulated rain acidified with sulphuric acid to pH 3.2 inhibited *Rhizobium* nodulation of leguminous plants (Shriner & Johnston 1981). Foliar applications of simulated acid rain (pH 2.0) reduced the biomass of *Platanus* and *Liquidambar* seedlings, both species native to eastern United States (Neufeld *et al.* 1985). There are numerous other studies that showed that acidity of rain has damaging effects on species diversity and productivity.

Recently the acidic deposition phenomenon has gained increasing attention especially when implicated as a factor responsible for economic loss of crops. Tamil Nadu is one of the states in India that consumes enormous quantity of coal as fuel. However, the effects of acid rain on soils and trees here have not been well documented. Hence, a pot culture experiment was carried out to document the impact of acid rain on the growth of *Acacia nilotica*, a dominant tree species found in the surroundings of many coal-based industries in Tamil Nadu.

MATERIALS AND METHODS

Pot culture experiment

A pot culture experiment was set up in this short-term study to determine the response and measurable effects of simulated acid rain on germination, growth and yield parameters of *A. nilotica*. The experiment was conducted at the Department of Environmental Sciences, Tamil Nadu Agricultural University (TNAU), Coimbatore, India using black and red soils. Black and red soils are the two dominant types of soils available in Tamil Nadu. The soils are different in chemical composition. Thus, to know the real impact of acidic solution on the dissociation and ionization of rhizosphere solute movement and foliar application of acidic solution impact on the morphology and growth of *A. nilotica* the pot culture experiment was conducted separately in both soils. We exclude ambient rainfall by conducting the experiment during the non-monsoon season, i.e. February till July 2003.

Soils for the experiment were gently pounded with a wooden mallet without crushing them to powder, sieved through a 2-mm wire mesh board to separate gravels and filled into pots to grow the test crop. The textural composition of black and red soil was analyzed using international pipette method (Piper 1966). The composite soil samples were analyzed for their chemical properties before and after treatment with simulated acid rain as per the standard methods.

Treatment chemistry

Five simulated acid rain solutions of pH 3.5, 4.5, 5.5, 6.5 and 7.0 were used in this study. The acid mixture was prepared in deionized water (pH 7.0) by mixing 70:30 (v/v) of 1 N each of H_2SO_4 and HNO_3 to maintain sulphate to nitrate ions ratio of 2:1 at each pH level(Anonymous 1985, Dubay & Heagle 1987). The pH matches the ambient rainwater chemistry of the different industrial locations in Tamil Nadu. The acid mixture was diluted to 5 l to arrive at the desired pH of simulated acid rain as indicated in Table 1. The simulated acid rain solutions were stored in polyethylene containers, closed with tight lid and kept at 4 °C in a freezer to avoid microbial contamination. Prior to dispensing, while imposing the foliar spray, the pH of simulated acid rain solutions was confirmed again with a pH meter (Elico LI 120).

Plant culture and simulation of acid rain

Acacia nilotica, local province type, was selected as test crop for foliar application of simulated acid rain. Six kilogram of black soil was filled into each 140 plastic pots (25 cm diameter × 25 cm height) to meet the requirement of treatment combination (5 treatments × 4 replication × 7 stages of sampling). The same quantity of red soil was filled into another set of 140 plastic pots to conduct the experiment similarly for comparison purposes. Only farmyard manure at 1.2 kg per pot was applied to *A. nilotica* before sowing of seeds. The seeds were pretreated by scarifying them with sulphuric acid at 200 ml kg^{-1} seeds to remove the hard coat. Five seeds were sown in each pot but only a single seedling was allowed to grow up to 45 days with normal irrigation water after which the seedling was subjected to simulated acid rain, each of different pH value, in a factorial completely randomized block design with four replications. The treatments were designated as T_1 (pH = 3.5), T_2 (4.5), T_3 (5.5), T_4 (6.5) and T_5 (7.0). The different treatments of simulated acid rain were imposed as foliar spray on the 45-day-old tree seedlings for 15 min during early hours of the day using a hand sprayer (Atlantic swivel Atomizer 450 ml capacity) fitted with stainless steel nozzles at normal pressure, approximately 1.0 m above the plants, which produced droplets ranging in diameter from 0.20 to 0.40 mm. The quantity of simulated rainwater used was 350 ml to cover a set of 28 potted plants in each set of treatment per soil type. Treatments were carried out for a period of 25 days in 10 spells to mimic the natural spell of rainfall in a monsoon, which covered seedlings at the ages of 45, 48, 50, 52, 55, 57, 60, 62, 68 and 70 days after sowing. Plant samples were taken at an interval of 15 days from the start of first exposure to simulated acid rain (i.e 45 days after sowing) up to135-day-old seedlings.

Measurements and observations

Plants were carefully uprooted, starting from 45 days after sowing as initial stage of sampling (0 day) to 135 days (i.e. 90 days after imposing treatment) at an interval of 15 days to examine the symptoms attributed to simulated acid rain and to determine the lengths and fresh weights of shoots and roots. The morphological parameters like plant height, root length, leaf number and dry matter accumulation were measured as per the standard methods. The leaf area was measured by Licor-model 3100 leaf area meter and the single leaf size and specific leaf area were calculated using leaf area $plant^{-1}$, number of leaves and leaf weight. The leaf area index, leaf area ratio and crop growth rate were calculated using the formula by Williams (1946), Radford (1967) and Watson (1958) respectively.

All the above morphological and growth parameters were measured initially before the exposure of simulated acid rain and also at 0, 15, 30, 45, 60, 75 and 90 days after imposing treatment from the pots of 45-, 60-, 75-, 90-, 105-, 120- and 135-day-old plants. The mean value of four replications observed in all stages of sampling were statistically analyzed for significant treatment effects. The critical differences were

Table 1 Composition of simulated acid rain solutions (5l) at different pH values

Simulated acid rain (pH)	Volume of acid mixture used (ml)	H^+ (μg l^{-1})	SO_4 (mg l^{-1})	NO_3 (mg $^{-1}$)
3.5	158.0	0.3160	16.4	8.3
4.5	16.0	0.0032	3.16	1.86
5.5	1.5	0.0003	1.28	0.57
6.5	0.5	0.0001	0.74	0.29
7.0 *	0.0	0.00	0.00	0.00

* Deionized water

worked out at 0.05 probability level as suggested by Panse and Sukhatme (1985).

RESULTS

Morphological and growth characters of *A. nilotica*

The morphological and growth parameters of *A. nilotica* exposed to simulated acid rain were measured and the mean values are presented in Tables 2 and 3. In general, visual symptoms of foliar injury were not observed on plants in both soils in any of the treatments. Similarly, no nodulation was seen on the root of the plants exposed to the simulated acid rain. We observed that for every one unit increase in pH, there was a proportionate increase in plant height. For the black soil, the increment was more at pH 5.5 (32.0 cm) compared with pH 3.5 (20.8 cm). Increased plant height with simulated acid rain at pH 7.0 showed enhanced potential in generating more number of leaves per plant, i.e. with 1069 leaves compared with pH 5.5 and 4.5 with 577 leaves and pH 3.5, 155. Data on root length revealed that it also followed the similar pattern of plant height with 14.4 cm at pH 5.5 compared with 10.2, 12.5 and 24.6 cm at pH 3.5, 4.5 and 7.0 respectively. Total plant dry matter accumulation contributed by leaf, stem and root showed that simulated acid rain at pH 3.5 decreased the total dry matter accumulation (10.0 g plant^{-1}) most than the rest of the pHs, i.e. of 11.0, 12.2, 14.2, 15.7 g plant^{-1} for pH 4.5, 5.5, 6.5 and 7.0 respectively. Along with decreased plant height and number of leaves, reduced cell division at lower pH contributed to smaller leaf size, specific leaf area and leaf area index. Crop growth rate indicated that the various treatments significantly influenced the crop growth rate. The foliar spray of simulated acid rain at pH 3.5 contributed more stress on morphological and growth characters. Seedling growth rates in black soil were only 2.24, 2.72, 2.85, 4.14 and 4.68 g m^{-2} day^{-1} at pH 3.5, 4.5, 5.5, 6.5 and 7.0 respectively(Table 2).

Table 2 Effects of simulated acid rain on growth and morphology of *Acacia nilotica* on black soil

Parameters	pH					CD (0.05)
	3.5	4.5	5.5	6.5	7.0	
Plant height (cm)	18.7 (8.5)	20.8 (8.3)	32.0 (8.5)	35.9 (8.5)	48.4 (8.5)	1.57
Root length (cm)	10.2 (3.84)	12.5 (3.48)	14.4 (3.60)	20.7 (3.70)	24.6 (3.78)	0.72
Leaf number (per plant)	155 (62)	208 (64)	577 (68)	737 (67)	1069 (73)	17.7
Leaf dry weight (g plant^{-1})	1.44 (0.91)	1.65 (0.94)	1.77 (0.91)	2.18 (0.94)	2.31 (0.95)	0.05
Stem dry weight (g plant^{-1})	5.88 (2.11)	6.36 (2.13)	6.61 (2.26)	8.15 (2.12)	8.91 (2.14)	0.10
Root dry weight (g plant^{-1})	2.71 (1.09)	2.95 (1.07)	3.78 (1.07)	4.35 (1.06)	4.60 (1.08)	0.05
Total dry matter accumulation (g plant^{-1})	10.0 (4.11)	11.0 (4.14)	12.2 (4.24)	14.2 (4.12)	15.7 (4.17)	0.12
Leaf area (cm^2 plant^{-1})	4.86 (4.0)	6.31 (4.0)	24.9 (4.0)	28.1 (4.0)	47.8 (4.0)	0.25
Single leaf size (cm^2 leaf^{-1})	0.04 (0.06)	0.04 (0.06)	0.10 (0.05)	0.10 (0.06)	0.14 (0.05)	0.004
Specific leaf area (cm^2 g^{-1})	3.49 (4.40)	3.98 (4.26)	15.0 (4.40)	14.5 (4.26)	23.6 (4.21)	0.22
Leaf area index	0.01 (0.01)	0.01 (0.01)	0.04 (0.01)	0.04 (0.01)	0.08 (0.01)	0.0004
Leaf area ratio	0.56 (0.73)	0.67 (0.97)	2.48 (0.94)	2.53 (0.97)	4.12 (0.96)	0.04
Seedling growth rate (g m^{-2} day $^{-1}$)	2.24 (1.52)	2.72 (1.54)	2.85 (1.52)	4.14 (1.52)	4.68 (1.52)	0.08

Note:
All the values indicate the mean value of stages and replication of plants.
Values in parenthesis indicate the initial value of the character measured before exposure to simulated acid rain at 45 days after planting.
CD = critical differences
Stage mean values alone compared by LSD and CD worked out at p = 0.05.

Table 3 Effects of simulated acid rain on growth and morphology of *Acacia nilotica* on red soil

Parameters	pH					CD (0.05)
	3.5	4.5	5.5	6.5	7.0	
Plant height (cm)	24.9 (8.7)	27.3 (8.7)	37.7 (8.6)	42.9 (8.7)	41.2 (8.7)	1.77
Root length (cm)	11.3 (4.18)	16.5 (4.12)	17.7 (4.16)	24.4 (4.18)	29.0 (4.19)	0.76
Leaf number (per plant)	225 (73)	262 (71)	672 (76)	824 (76)	1206 (72)	12.2
Leaf dry weight (g plant^{-1})	1.56 (0.86)	1.75 (0.92)	1.88 (0.90)	2.23 (0.93)	2.42 (0.93)	0.03
Stem dry weight (g plant^{-1})	6.09 (2.19)	6.51 (2.19)	6.95 (2.20)	7.82 (2.20)	8.79 (2.14)	0.09
Root dry weight (g plant^{-1})	2.69 (1.04)	3.07 (1.08)	3.93 (1.10)	4.50 (1.05)	4.67 (1.11)	0.04
Total dry matter accumulation (g plant^{-1})	10.3 (4.09)	15.6 (4.19)	12.8 (4.20)	14.5 (4.18)	15.9 (4.18)	0.10
Leaf area (cm^2 plant^{-1})	12.3 (9.8)	16.2 (9.6)	38.7 (9.8)	57.7 (9.8)	85.8 (9.8)	0.56
Single leaf size (cm^2 leaf^{-1})	0.08 (0.13)	0.09 (0.13)	0.14 (0.13)	0.17 (0.13)	0.26 (0.13)	0.008
Specific leaf area (cm^2 g^{-1})	8.25 (11.3)	10.1 (10.4)	22.2 (10.8)	27.3 (10.5)	41.8 (10.5)	0.51
Leaf area index	0.02 (0.02)	0.02 (0.02)	0.06 (0.02)	0.08 (0.02)	0.13 (0.02)	0.0017
Leaf area ratio	1.41 (2.39)	1.72 (2.29)	3.77 (2.33)	4.83 (2.34)	7.39 (2.34)	0.06
Seedling growth rate (g m^{-2} day^{-1})	2.57 (1.71)	2.92 (1.70)	3.18 (1.70)	4.17 (1.72)	4.79 (1.72)	0.13

Note:
All the values indicate the mean value of stages and replication of plants.
Values in parenthesis indicate the initial value of the character measured before exposure to simulated acid rain at 45 days after planting.
CD = critical differences
Stage mean values alone compared by LSD and CD worked out at p = 0.05.

Simulated acid rain on red soil also reduced plant height at pH 3.5 with a value of 24.9 cm but increased to 37.7 cm at pH 5.5 and 41.2 cm at pH 7.0 (Table 3). Due to reduced height at pH 3.5 the plants showed lower number of leaves (225) than at pH 7.0 (1206). Root length was also lower at lower pH (11.3 cm at pH 3.5, 17.7 cm at pH 5.5 and 29.0 cm at pH 7.0). Just as in black soil, decreased capability in formation of plant parts at lower pH as a result of simulated acid rain affected plant growth at lower pH. Single leaf size and total dry matter production were 0.08 cm^2 leaf^{-1} and 10.3 g plant^{-1} at pH 3.5 compared with 0.26 cm^2 leaf^{-1} and 15.9 g plant^{-1} respectively at 7.0 pH. Bigger leaf size and increased leaf number contributed to enhanced leaf area of 85.8 cm^2 plant^{-1} at 7.0 pH compared with 12.3 cm^2 plant^{-1} at pH 3.5. Leaf area ratio and specific leaf area also showed similar patterns, i.e. being higher at pH 7.0 with values reaching 7.39 and 41.8 cm^2 g^{-1} respectively. Higher stress level at lower pH resulted in reduced crop growth rate, i.e. 2.57 g m^{-2} day^{-1} at pH 3.5 compared with 2.92, 3.18, 4.17 and 4.79 g m^{-2} day^{-1} at pH 4.5, 5.5, 6.5 and 7.0 respectively. Generally, the intensity of stress caused by simulated acid rain on *A. nilotica* was more on red soil than on black and this might be due to the influence of soil media characters and its nutrient transformation.

Effects of simulated acid rain on soil chemical properties

The composite soil samples were analyzed for their chemical properties before and after treatment with simulated acid rain and changes in soil nutrients are tabulated in Table 4. The soil chemical analysis revealed that black soil used in the experiment was clay loam in texture whereas the red soil belonged to sandy loam. Physical constants of the soils showed that there were no marked differences in the bulk density and particle density between soils. The pH of black and red soils decreased at the end of the experiment; under simulated rain of pH 3.5 the pH decreased from 8.5 to 7.8 and from 7.8 to 7.0

Table 4 Chemical properties of soil at the end of the study

Soil parameter	Black soil						Red soil						CD (0.05)
	Initial	pH					Initial	pH					
		3.5	4.5	5.5	6.5	7.0		3.5	4.5	5.5	6.5	7.0	
Soil pH	8.5	7.8	7.9	7.9	8.1	8.4	7.8	7.0	7.1	7.2	7.3	7.4	0.07
Soil EC* (dsm^{-1})	2.60	1.75	1.34	1.64	1.05	0.77	1.80	1.57	2.18	2.36	1.39	1.48	0.06
CEC(cmol (p^{+}) kg ha^{-1})	33.2	20.1	18.7	17.7	19.6	20.4	19.2	14.8	14.3	13.3	14.7	15.1	0.44
Organic matter (g kg^{-1} of soil)	9.97	7.98	8.16	8.05	7.26	7.45	7.05	6.48	6.85	6.67	6.08	6.39	0.16
Soil available nitrogen (kg ha^{-1})	200	131	131	139	174	170	178	141	128	151	146	169	6.19
Soil available phosphorus (kg ha^{-1})	11.0	6.26	6.28	6.67	8.32	7.21	9.0	6.74	6.13	7.27	7.00	9.06	0.30
Soil available potassium (kg ha^{-1})	418	257	262	258	337	292	386	252	298	278	284	366	11.3
Exchangeable calcium (cmol (p^{+}) kg ha^{-1})	18.2	11.5	10.2	10.0	11.0	12.1	10.0	8.72	8.06	6.77	7.54	8.04	0.34
Exchangeable magnesium (cmol (p^{+}) kg ha^{-1})	7.90	5.78	6.23	5.33	6.78	6.12	6.40	4.65	4.52	4.04	5.17	5.13	0.32
Exchangeable sodium (cmol (p^{+}) kg ha^{-1})	1.20	0.78	0.78	0.83	0.78	0.83	0.80	0.49	0.52	0.47	0.52	0.49	NS
Exchangeable potassium (cmol (p^{+}) kg ha^{-1})	0.90	1.45	1.26	1.40	1.18	1.18	1.30	1.18	1.28	1.59	1.34	1.37	NS
Exchangeable hydrogen (cmol (p^{+}) kg ha^{-1})	1.20	0.68	0.60	0.52	0.37	0.26	0.80	1.10	1.02	0.78	0.64	0.60	0.05
Exchangeable aluminium (cmol (p^{+}) kg ha^{-1})	0.90	1.62	1.45	1.24	0.84	0.63	1.30	1.92	1.91	1.51	1.04	0.87	0.08
Ca:Al molar ratio	13.5	5.41	5.36	5.82	8.90	12.8	5.13	3.15	2.93	3.03	4.85	5.36	0.49

*EC = Electrical conductivity

respectively. The EC of the soil was decreased from 2.60 to 0.77 dSm^{-1} in black soil compared with 1.80 to 1.48 dSm^{-1} in red soil at pH 7.0. Lower organic matter content in both soils at lower pH indicated that mineralization of organic matter had occurred. Available nitrogen, phosphorus and potassium in black soil decreased in pots that received acid rain of pH 3.5, i.e. from the level of 200, 11.0 and 418 kg ha^{-1} to 131, 6.3 and 257 kg ha^{-1}. In red soil, the values were from 178, 9.0 and 386 kg ha^{-1} to 141, 6.8 and 252 kg ha^{-1} respectively. No rhizobial nodules were noticed in the roots of plants irrespective of the soil and treatment. The cation exchange capacity (CEC) of the soil was significantly decreased in the treatment of pH 5.5, i.e. from 33.2 and 19.2 cmol (p^{+}) kg ha^{-1} to 17.7 and 13.3 cmol (p^{+}) kg ha^{-1} in black and red soils respectively. Exchangeable Ca and Mg showed significant variation with treatments but exchangeable Na and K were not affected. Exchangeable hydrogen significantly decreased in black soil but increased in red soil. At pH 3.5 the value reduced from 1.20 to 0.68 cmol (p^{+}) kg ha^{-1} in black soil but increased from 0.80 to 1.10 cmol (p^{+}) kg ha^{-1} in red soil. At the same pH, exchangeable aluminium increased from 0.90 to 1.62 cmol (p^{+}) kg ha^{-1} and 1.30 to 1.92 cmol (p^{+}) kg ha^{-1} in black and red soils respectively. High concentration of exchangeable aluminium in both soils at pH 3.5 might be the reason for poor root growth which affected shoot and morphological parameters of the plant. A molar ratio of Ca/Al below 1.0 is critical to plant roots (Cronan & Grigal 1995); the Ca/Al molar ratio calculated in the study was in the range of 12.8 to 5.41 in black soil and 5.13 to 2.93 in red soil.

DISCUSSION

In this study plant heights of *A. nilotica* on black and red soils after exposure to simulated acid rain with high acidity of 3.5 were 61.4 and 60.4% lower respectively compared with the treatment of pH 7.0. The variation might be due to differences in acidity level. A similar trend on plant height reduction in many forests and field crops under simulated acid rainfall events has been reported, e.g. by Singh and Agrawal (1996), Sonia and Khan (1996), Manju and Sanjay (1998) and Gadallah (2000). Under simulated rain of pH 3.5 the function of cell expansion seemed to be more sensitive than the function of cell division and this has caused the reduction in plant height. In contrast, Dixon and

Kuja (1995) observed more plant height in sugar maple seedlings subjected to moderate levels of acid rain than seedlings receiving normal rain (pH 5.6) and attributed this to possible enhancement of photosynthesis after exposure to acid rain.

Application of simulated acid rain on the test crop had a definite impact on root length. The root growth was mostly affected in red soil (61.0%) as compared with black soil (58.5%). This might be due to the high exchangeable aluminium present in the root zone of red soil which affected the growth and development of roots and, thus, causing root damage. However, in black soil sufficient amount of exchangeable bases was able to reduce the toxic effect of aluminium (Matzner & Murach 1995).

The effect of various pH levels of simulated acid rain water in accelerating leaf senescence has been well established. Leaf number decreased with increased acidity due to stress mechanism. Leaf growth is affected by simulated acid rain because of the reduction in transpiring area with little uptake of essential nutrients (Sonia & Khan 1996).

Total dry matter accumulation in both soils was substantially reduced by the acidity of simulated rain. The result of the present study corresponds with findings of Slavov and Joleva (1994) in maize crop. Clear treatment differences in leaf dry weight were expressed and the variation widened as *A. nilotica* seedlings recorded reduced leaf weight with simulated acid rain of pH 3.5 compared with pH 7.0. Even a mild dose of acidity caused significant reductions in stem weight because the functions of cell division and cell expansion were affected by acid rain stress (Sonia & Khan 1996). Senescence of root or loss of root tissue was very rapid as the intensity of acidity increased in the treatment of simulated acid rain. Increased acidity decreases the root dry weight because of redistribution of photosynthates. However, in the present study this is only true in the treatment of simulated acid rain of pH 3.5.

Expanding leaves were found to be extremely sensitive to simulated acid rain and even a small change in leaf cations was sufficient to cause reduction in leaf area (Shan *et al.* 1997). Severe reduction in leaf area at pH 3.5 might due to the low uptake of calcium and magnesium from the soil solution or the interference of aluminium ion with the availability of calcium and magnesium in the soil. In this study, generally, single leaf size decreased with increase in acidity level. These results are consistent with the findings of Singh and Agrawal (1996). Leaf expansion was visibly higher and there was a decrease in specific leaf area irrespective of soils. Consequently, the reduction in leaf area was proportional to the acidity level of the treatment. The trend clearly showed that the treatment at pH 7.0 recorded significantly higher leaf area than pH 3.5. Thus, lower expansion of leaf at lower pH affected the photosynthetic process.

Leaf area index showed a distinct difference between seedlings and treatments, with marked reductions at lower pH. Low leaf area index was due to cell enlargement to even slight acidity (Gadallah 2000). Reduced leaf area ratio at higher acidity was noticed in both soils. A lower leaf area ratio would mean lower dry matter accumulation (Slavov & Joleva 1994, Sonia & Khan 1996). Seedling growth rate was highest when maximum leaf area was observed. It might be inferred that at pH 3.5 leaf and stem growth stopped completely at initial stage of growth period which resulted in reduced crop growth rate (Heagle *et al.* 1983).

There is a growing concern about the effects of simulated acid rain on soils. Once the soil is acidified, it can considerably affect the soil environment, which in turn controls the nutrient flow to the root zone of crops. In general this study showed that increased acidity caused accelerated losses of mineral bases from soils and subsequent losses in productivity. Simulated acid rain significantly reduced soil pH by about 1.0 unit in both soils. This might be due to the addition of hydrogen ion through simulated acid rainfall (Robarge & Johnson 1992, Walna *et al.* 2000). The pH decrease in turn increased electrical conductivity (EC) of the soil in both soils but lower in the black soil due to its higher buffering capacity.

Fertility of soil mainly depends on the soil organic matter present in it. In the study, the treatment of simulated acid rain of pH 5.5 had high soil organic matter due to higher carbon content. The cation exchange capacity (CEC) of the soil is an index for exchangeable bases, namely, calcium, magnesium, sodium and potassium. The various treatments in this study significantly influenced the status of CEC in both soils although marked variation was observed in the red soil compared with black.

The growth of any crops on soil medium is mainly determined by the availability of major nutrients, namely, nitrogen, phosphorus and potassium. Soil available nitrogen was highest at pH 7.0 because of the effects of acidity on soil enzymatic activities that in turn influenced the growth of soil microorganism and their ability in soil mineralization. The soil available phosphorus was high at pH 6.5 and 7.0 in black and red soils respectively. High available phosphorus might be due to the influence of pH on the soil microflora. At lower pH soil microflora converts unavailable form of phosphorus into its available form. In treatments of high acidity, less available phosphorus was observed due to reduced level of microflora and in so resulted in reduced level of conversion of unavailable phosphorus into its available form (Walna *et al.* 2000). Soil available potassium, which was also influenced by soil microflora, also showed the same trend as phosphorus in the study.

Exchangeable calcium and magnesium in both soils were highest at pH 7.0. At higher pH, less bases in the surface are removed by free hydrogen ion. At higher pH a decrease in calcium and magnesium levels was observed because the free action of hydrogen caused leaching of calcium and magnesium into subsurface soil. Exchangeable sodium and potassium in both soils were not altered by various treatments of simulated acid rain in the study. This might be due to the affinity of hydrogen ion to monovalent form of sodium and potassium. In the study, the various treatments of simulated acid rain greatly influenced the divalent rather than monovalent cations and this supports the findings by Walna *et al.* (2000).

Exchangeable hydrogen was higher at pH 3.5 than pH 7.0. At higher acidity, more deposition of free hydrogen occurs from the acid mixture to the surface soil. This is also the reason for the higher exchangeable hydrogen in red soil which is dominated with iron and aluminium oxides compared with black. Exchangeable aluminium was also higher following the treatment of simulated acid rain at pH 3.5 due to the release of monomeric aluminium from the soil clay into the root zone (Seip 1980).

An important parameter for assessing the impact of acidity on soil is the measure of soil calcium/aluminium ratio. A lower ratio will indicate a higher level of aluminium ions which toxic effect can cause root damage (Cronan & Grigal 1995). The calcium/aluminium ratios observed in this study were in the range of 2.93 to 12.8. Red soil showed lower ratio because of the lower quantity of calcium ions.

CONCLUSIONS

Many environmental stress factors play important roles on the influence of morphological and growth parameters of *A. nilotica* on black soil and red soil. Our pot culture experiment using black and red soils showed that the foliar application of simulated acid rain at pH 3.5 significantly reduced morphological and growth characters, namely, plant height, root length, leaf number, total dry matter accumulation, leaf area, single leaf size, specific leaf area, leaf area index, leaf area ratio and crop growth rate. In red soil, high exchangeable aluminium present in the root zone affected the growth and development of roots causing root damage whereas in black soil, sufficient amount of exchangeable bases reduced the toxic effect of aluminium. However, the results underline the need for further studies of the consequences of prolonged exposure of acidic rainfall on ecosystem.

ACKNOWLEDGEMENT

Thanks are due to P. P. Ramasamy from the Tamil Nadu Agricultural University for his constant help and valuable suggestions during the study period.

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