Effects of pH Amendment and Fertilizer Application on Root Growth of Maize (*Zea mays* L.) in Tropical Peat Soil

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Received November 18, 1996

Abstract

Field experiments were conducted to determine how pH amendment and fertilizer application influence the root growth of maize (*Zea mays* L., cv. Masmadu) in an acidic peat soil. Five fertilizer treatments (0, NK, PK, NP and NPK) at four levels of lime application were designed in a field with woody peat of the Malaysian Agricultural Research and Development Institute (MARDI) Jalan Kebun Station. The growth of maize was very poor without soil pH amendment due to the inhibition of root growth by the high acidity of the soil, even though NPK fertilizers were applied. Maize roots did not grow into acidic layers of soil with a pH below 3.8, even when the soil was amended with ground magnesium limestone (GML) and NPK fertilizers, indicating that the rhizosphere volume was limited by the depth of soil pH amendment. Soil pH amendment, on the other hand, stimulated root growth and shoot growth. NPK fertilizers, particularly nitrogen and phosphorus fertilizers exerted a beneficial effect on the root growth in the presence of GML. There was a significant positive correlation between the root growth and shoot growth at the vegetative growth. Grain yield for fresh vegetable use ranged from 179 to 1,810 kg ha^{-1}, and the maximum yield was obtained in the NPK plot with 25 t ha^{-1} GML application.

Additional key words : acid soil, liming, root growth, tropical agriculture

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Introduction

More than 20 million ha of lowland peat soil occur in tropical Southeast Asia[7] of which about 2.4 million ha are located in Malaysia[18]. Despite their numerous limitations and constraints on crop growth, there has been an increasing demand to develop peat soil swamps for agriculture[12, 18]. Peat soil is highly acidic with a pH value ranging from 3.5 to 4[12, 15, 16]. Liming for crop cultivation has been a common practice for peat soil agriculture, since almost all the crops are unable to grow properly in such a strongly acidic medium[16]. Several papers have been published on the effect of pH amendment of peat soil on growth performance as reviewed by Leong *et al.* for tropical peat soil[16]. However, most of the studies dealt with top growth and/or yield[3-6, 11, 13, 14] and there have been very few reports on root growth. Roots play the role of an interface between shoot growth and soil[9] and may be affected directly by the high acidity of peat soil. It is generally recognized that hydrogen ion in low pH media inhibits plant root elongation[2] and that root growth of many plants could be ameliorated by increasing the calcium content in a medium with low pH[9].

Plant nutrients in tropical woody peat soils have been known to be very poor as evidenced by the very low ash content ranging from 1 to 3 % in the natural state and by the very low bulk density, leading to a very small amount of nutrients in a unit soil profile[12]. The effects of macro- and micro-nutrients in chemical fertilizers on the growth performance of many crops have been well documented[1, 5, 6, 11, 14]. However, data of measurement of root growth in such studies are usually not available. The purpose of our study was to determine how root growth can be affected by NPK fertilizers and pH amendment with ground magnesium limestone (GML) for liming.

We used maize as test crop since maize is a moderately tolerant crop to acid soil[24] and maize for vegetable grain use appears to be one of the promising crops in Malaysia.

Another object of the present field experiment was to examine the effect of soil pH amendment and NPK fertilization on the decomposition of peat soil organic matter, since the decomposition leads to an irreversible loss of soil resources, resulting in surface subsidence which is highly detrimental and cannot be readily improved for sustainable agriculture on peat soil. The results have been reported in other papers[19, 20].

Materials and Methods

Soil properties and cultivation practice

Maize (*Zea mays* L.) variety Masmadu for fresh grain vegetable use was grown on woody peat soil in a field of MARDI Jalan Kebun Station. The field had been previously used for oil palm cultivation for about 15 years. After improvement for annual crop cultivation, the field had been used for pineapple cultivation for three years and one cropping of maize, baby- corn for vegetable. Soil pH, carbon content, nitrogen content, ash content, electric conductivity (EC) and bulk density were 3.8, 56.5%, 1.44%, 6.0%, 0.11 mS cm^{-1} and 0.29 g cm^{-3}, respectively. The soil is classified as hyperthermic tropohemists in the Soil Taxonomy and is oligotrophic[10].

Lime treatment for pH amendment consisting of four levels, 0 (L0), 12.5 (L1), 25.0 (L2) and 50.0 t ha^{-1} (L3) of GML was carried out on February 9 in 1992. Basal fertilizers were applied at the rate of 140 kg N, 60 kg P_2O_5, 100 kg K_2O ha^{-1} as urea, triple superphosphate and muriate of potash, respectively on February 27. Micro-nutrients were not used for the present field experiments, due to the residual effects of the micro-nutrients applied for the previous cropping of baby- corn in the same field. Maize seeds were sown on March 6 at a spacing of 70 x 40 cm in a 8.4 x 8.0 m plot. At 21 days after sowing (DAS), plants were thinned to one per hill.

Measurement of plant growth and grain yield

Stem diameter and plant height were measured in the field to evaluate the growth performance at 21, 35 and 70 DAS, and 5-10 plants from one plot were sampled for the measurement of dry weight, except for 21 DAS when 29 plants were sampled. Grain yield was estimated for the sample of 81 DAS when the grain for vegetable use was not yet completely mature. All the dry weights were measured after oven drying at 70°C.

Measurement of root growth

Roots of two plants per plot were carefully dug up together with soil at intervals of 5 cm depth down to 25 cm in the soil profile 70 x 40 cm in area surrounding the hill at 35 DAS. At the same time 5 plants per plot including the root sampling hill were taken for measurement of top growth. Roots were carefully separated, soil was washed out and the roots were dried in an oven at 70°C. The soil separated from roots was used for the measurement of the pH in water suspension (1:2.5).

Measurement of soil pH, EC and ground water level

Samples for the measurements of the soil acidity (pH) and electric conductivity (EC) were taken from the surface soil to a depth of 10 cm at 9 zones per plot and mixed. Ground water level was measured with an electric tester which reacted to the ground water pooled inside a plastic tube installed vertically into soil at a 150 cm depth.

Results and Discussion

Soil acidity (pH) and electric conductivity (EC)

Soil pH increased shortly after GML application, and the initial pH values at 4 days after liming were 3.96 (L0), 4.53 (L1), 5.42 (L2) and 6.03 (L3), indicating that the pH increased almost in parallel with the amount of GML applied until the L2 level, but that the effectiveness of liming on pH amendment was reduced at the L3 level application (Fig. 1). It was also shown that even such a very high level of liming (50 t GML ha^{-1}) did not completely neutralize the peat soil acidity. The very high level of lime application was aimed primarily at ensuring that the pH amendment would be effective on the decomposition of peat soil organic matter, as reported in other papers[19, 20]. The soil acidity of tropical oligotrophic woody peat in the natural state is lower than pH 4.0, due to the high content of exchangeable hydrogen[26], and the lime requirement is high because of the high buffering capacity of peat soil[16]. The effect of GML liming on pH amendment lasted a long time during the present period of maize cultivation, and also at least another 5 months when the soil was not ploughed thereafter (pH measurement was continued but the data were omitted here).

The effects of NPK fertilizer application on soil pH were inconsistent among the liming levels (Fig. 1). Soil pH of the NPK plot was slightly higher than that of the plot without NPK application at L2 and L3 GML levels, 3 and 16 days after NPK application. However, the effect of NPK for the lowest liming level (L1) was not consistent. Furthermore, the soil pH of the L0 plot was almost the same, regardless of the application of NPK fertilizers.

Changes in soil EC differed from those of soil pH (Fig. 2). Increase in EC due to GML application for the L1 level which was negligible was conspicuous for the L2 and L3 levels of application. NPK fertilization increased the EC of the soil regardless of the liming levels, and EC reached maximum values 16 days after NPK application, then decreased gradually and

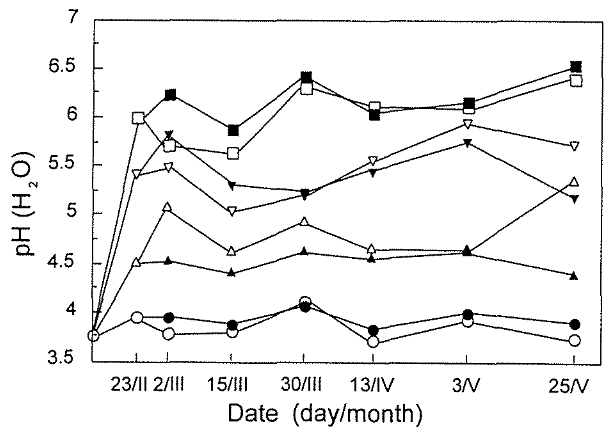

Fig. 1. Changes in soil acidity (pH) during the period from liming to harvest (○:L0(0),●:L0(NPK), △:L1(0), ▲:L1(NPK), ▽:L2(0), ▼:L2(NPK), □:L3(0), ■:L3(NPK))

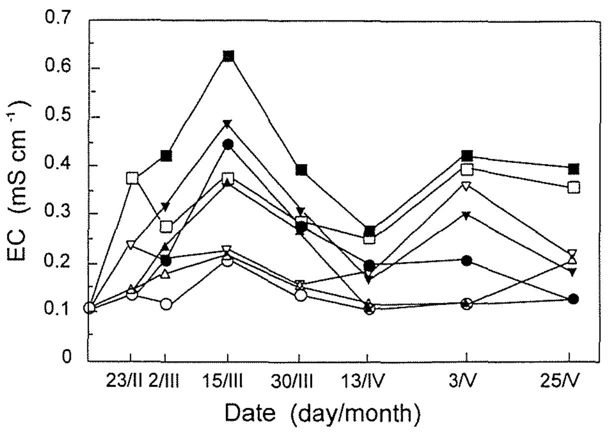

Fig. 2. Changes in electric conductivity (EC) of soil during the period from liming to harvest (○:L0(0), ●:L0(NPK), △:L1(0), ▲:L1(NPK), ▽:L2(0), ▼:L2(NPK), □:L3(0), ■:L3(NPK))

significantly. The decline may be ascribed to the fact that the dissolved nutrient elements from NPK had been taken up by maize, and some part of the elements had eluviated down to deeper layers of the soil profile and/or was complexed with functional groups of peat soil organic matter into a non- dissociative form. Maximum EC values observed in the NPK plot with GML at L3 level was 0.63 mS cm^{-1}, a lower value than the critical value for proper crop growth[8)].

Growth of maize and grain yield

Growth performance of maize was extremely poor without pH amendment, even though NPK fertilizer was applied (Table 1). Establishment of the seedlings was not adequate without liming (L0), and more than half of the plants in this plot died before tasseling, and could not produce corn-cob/grain, even when NPK was applied (Table 2). These finding were in agreement with the results reported by Ambak *et al.*[1)] in another Malaysian peat soil. Effect of soil pH amendment on the

Table 1. Stem diameter (SD) and plant length (PL) of maize at 21 and 35 days after sowing (DAS)

Treatment		21 DAS						35 DAS					
		SD (mm)			PL (cm)			SD (mm)			PL (cm)		
L0	0	1.8	(45)[a)]	(40)[b)]	20	(48)	(47)	3	(35)	(20)	27	(44)	(28)
	PK	2.4	(60)	(35)	26	(62)	(45)	4	(49)	(22)	36	(60)	(30)
	NK	3.5	(88)	(64)	36	(86)	(76)	7	(88)	(40)	52	(85)	(46)
	NP	3.6	(90)	(51)	39	(93)	(65)	8	(94)	(39)	57	(93)	(44)
	NPK	4.0	(100)	(50)	42	(100)	(64)	8	(100)	(37)	62	(100)	(40)
L1	0	4.1	(52)	(91)	38	(59)	(90)	12	(53)	(79)	79	(52)	(81)
	PK	5.8	(73)	(85)	50	(78)	(89)	17	(77)	(90)	101	(66)	(84)
	NK	4.9	(62)	(89)	41	(64)	(88)	19	(87)	(104)	120	(79)	(106)
	NP	6.4	(81)	(91)	53	(82)	(89)	20	(90)	(97)	126	(83)	(97)
	NPK	7.9	(100)	(99)	64	(100)	(100)	22	(100)	(97)	152	(100)	(99)
L2	0	4.5	(56)	(100)	43	(66)	(100)	15	(66)	(100)	98	(64)	(100)
	PK	6.8	(85)	(100)	56	(88)	(100)	19	(83)	(100)	120	(78)	(100)
	NK	5.5	(69)	(100)	47	(72)	(100)	19	(81)	(100)	113	(73)	(100)
	NP	7.0	(88)	(100)	59	(92)	(100)	20	(89)	(100)	130	(84)	(100)
	NPK	8.0	(100)	(100)	64	(100)	(100)	23	(100)	(100)	154	(100)	(100)
L3	0	4.7	(49)	(100)	43	(73)	(102)	16	(75)	(110)	105	(73)	(107)
	PK	6.9	(72)	(101)	57	(96)	(101)	20	(94)	(107)	126	(88)	(105)
	NK	5.8	(60)	(105)	50	(83)	(106)	19	(87)	(103)	113	(79)	(100)
	NP	7.5	(78)	(107)	62	(105)	(105)	22	(102)	(109)	149	(104)	(115)
	NPK	9.6	(100)	(120)	59	(100)	(92)	22	(100)	(96)	143	(100)	(93)

[a)]Figures in the parenthesis denote relative value to fertilizer treatment at NPK at each lime level.
[b)]Figures in the parenthesis denote relative value to each fertilizer treatment at L2.

Table 2. Shoot dry matter (SDM) of maize at 21, 35 and 70 days after sowing (DAS) and grain yield (GY) at harvest

Treatment		SDM (g $plant^{-1}$) 21 DAS	SDM (g $plant^{-1}$) 35 DAS	SDM (g $plant^{-1}$) 70 DAS	GY (kg ha^{-1})
L0	0	0.09 (19)[a] (13)[b]	0.2 (13) (3)	0 (0) (0)	0 (0) (0)
	PK	0.14 (31) (9)	0.6 (30) (5)	0 (0) (0)	0 (0) (0)
	NK	0.30 (65) (32)	0.7 (35) (7)	0 (0) (0)	0 (0) (0)
	NP	0.39 (85) (20)	0.9 (45) (4)	0 (0) (0)	0 (0) (0)
	NPK	0.46 (100) (21)	2.0 (100) (5)	0 (0) (0)	0 (0) (0)
L1	0	0.48 (19) (70)	4.7 (13) (59)	31 (27) (61)	179 (11) (58)
	PK	0.91 (36) (57)	13.2 (37) (104)	46 (40) (79)	236 (15) (61)
	NK	0.58 (23) (62)	12.2 (34) (122)	78 (68) (102)	597 (37) (62)
	NP	1.25 (49) (64)	21.8 (60) (100)	111 (97) (103)	1046 (65) (77)
	NPK	2.53 (100) (115)	36.1 (100) (84)	115 (100) (87)	1618 (100) (89)
L2	0	0.69 (32) (100)	8.1 (19) (100)	51 (66) (100)	309 (17) (100)
	PK	1.59 (72) (100)	12.7 (30) (100)	58 (44) (100)	389 (22) (100)
	NK	0.93 (42) (100)	10.0 (23) (100)	77 (58) (100)	960 (53) (100)
	NP	1.94 (88) (100)	21.7 (51) (100)	108 (82) (100)	1353 (98) (100)
	NPK	2.20 (100) (100)	42.8 (100) (100)	132 (100) (100)	1810 (100) (100)
L3	0	0.69 (40) (100)	9.9 (28) (123)	46 (36) (91)	442 (26) (143)
	PK	1.60 (92) (101)	15.5 (43) (122)	76 (59) (131)	761 (44) (196)
	NK	1.10 (63) (118)	14.5 (41) (145)	83 (65) (108)	997 (58) (104)
	NP	2.15 (123) (111)	29.1 (81) (134)	139 (108) (129)	1749 (102) (129)
	NPK	1.74 (100) (79)	35.7 (100) (83)	129 (100) (98)	1710 (100) (94)

[a]Figures in the parenthesis denote relative value to fertilizer treatment at NPK at each lime level.
[b]Figures in the parenthesis denote relative value to each fertilizer treatment at L2.

growth of maize was obvious until harvest, but the largest application of GML did not always result in optimum growth, particularly in the NPK-amended plots (Table 2).

There were no noticeable symptoms of deficiency in micro-nutrients in all the treatment including that without liming. However, plants lacking nitrogen became yellowish and growth was usually poor among fertilizer treatments at every liming level (Tables 1 and 2). This condition may be ascribed to the very small amount of available nitrogen in peat soil, since the decomposition of peat soil organic matter was extremely slow[19] and the absolute amount of nitrogen per unit area was very small, due to the very low bulk density, 0.29 g cm^{-3}, even when the soil nitrogen content was as high as 1.44%.

Effects of NPK fertilizers on maize growth were obvious irrespective of the liming level. The effect of the fertilizers applied on the growth of maize at 35 DAS was in the following order; 0<< NK<PK<<NP<NPK, suggesting that phosphorus may be more important for the initial growth stage than nitrogen in this soil (Table 2). The same response of shoot growth to fertilizer treatments was observed in tomato at the vegetative stage[14]. However, shoot growth at harvesting time and grain yield responded in the following order; 0<<PK<NK<NP<NPK, suggesting that nitrogen was limiting at this stage, which corresponded to the observations of pot and field experiments of maize in another tropical peat soil[22].

Maximum grain yield was obtained for the 25 t GML ha^{-1} application, and liming at the rate of 50 t ha^{-1} was considered to be too high to obtain proper growth of maize (Table 2). This phenomenon may be due to the adverse effects of excessive Ca application on the uptake of nutrients, as it has been reported that the addition of large quantities of lime or GML depressed the plant uptake of phosphorus[6, 14, 17] and potassium[14].

Growth of Roots

To correlate the grain yield and/or top growth with root growth, root weight was measured and the distribution of roots in the soil profile was examined at the vegetative growth stage. The lowest value for root weight was observed in the plot without application of both GML and NPK (Table 3). Liming with GML improved significantly the root growth, irrespective of the difference in the fertilizer treatments. Root growth in the NPK treatment was more satisfactory than without NPK regardless of the rate of GML application.

Table 3. Root dry matter (RDM) per plant of maize at 35 days after sowing

Treatment		RDM (g plant^{-1})		
L0	0	0.08	(15)[a]	(6)[b]
	PK	0.09	(17)	(3)
	NK	0.37	(68)	(23)
	NP	0.11	(20)	(4)
	NPK	0.54	(100)	(11)
L1	0	0.99	(22)	(69)
	PK	2.42	(53)	(90)
	NK	1.79	(39)	(111)
	NP	2.74	(60)	(94)
	NPK	4.60	(100)	(93)
L2	0	1.44	(29)	(100)
	PK	2.68	(54)	(100)
	NK	1.61	(33)	(100)
	NP	2.91	(59)	(100)
	NPK	4.92	(100)	(100)
L3	0	1.53	(30)	(106)
	PK	2.84	(56)	(106)
	NK	1.77	(35)	(110)
	NP	4.51	(89)	(155)
	NPK	5.07	(100)	(103)

[a]Figures in the parenthesis denote relative value to fertilizer treatment at NPK at each lime level.
[b]Figures in the parenthesis denote relative value to each fertilizer treatment at L2.

No roots were detected at a soil depth below 20 cm and about 60 to 90% of the total roots were distributed in the surface layer at a 5 cm depth in all the treatments (Table 4). The roots never grew into the acidic layer of soil below a pH value of 3.8, even though the surface ploughed layer was limed and fertilized. These findings corresponded to the results obtained by Yan *et al.*[25]. They showed that pH 3.5 was critical value at which root growth of maize ceased. The strong inhibitory effect of soil acidity could be ascribed to the hydrogen ions of peat soil organic matter which were unsaturated with base ions such as Ca[2+25]. Adverse effects of excessive moisture of the ground water on root penetration into the deeper layers could be ruled out, since the maximum level of ground water was larger than 45 cm.

Maize roots developed well in the pH-amended surface layer, probably due to the presence of Ca in GML which in maize promotes root growth[9] and the development of a longer and finer root system[21]. In addition, the physiological function of Ca at low pH medium was reported in detail by Yan *et al.*[25].

Relationships among soil pH, fertilizer treatment and root growth are depicted in Fig. 3, and the effects of fertilizer on root growth, particularly of nitrogen and phosphorus were clearly observed in the presence of GML. This observation suggests that pH amendment and fertilizer application are essential factors for better growth of maize in peat soil. In fact, the availability of nitrogen from peat was very low due to the slow decomposition and phosphorus deficiency also occurred in peat soil[11]. Although liming using GML has been reported to increase the availability of phosphorus in peat soil[6], the amount of available phosphorus could not meet the requirements for maize growth.

There was a significant positive correlation between root growth and shoot growth measured at 35 DAS and the relation was observed irrespective of the pH amendment and NPK treatment (Fig. 4). The poor root grov h in acidic soil without liming resulted in the increase of plant

Table 4. Root distribution (RD) and soil acidity (pH) at different depths at 35 days after sowing

Treatment	Layer[a)]	Ground magnesium limestone (t ha^{-1})							
		0		12.5		25.0		50.0	
		pH	RD (%)	pH	RD (%)	pH	RD (%)	pH	RD (%)
0	1	3.84	91.5	4.44	58.1	5.13	60.4	5.80	74.4
	2	3.84	8.5	4.38	23.9	5.00	24.6	5.66	16.8
	3	3.86	0	4.47	16.2	4.63	13.1	5.32	8.5
	4	3.70	0	4.20	1.8	3.94	1.8	4.32	0.2
	5	3.70	0	3.89	0	3.84	0	3.86	0
PK	1	3.89	84.0	4.57	70.4	4.86	54.4	5.81	64.0
	2	3.86	16.0	4.38	20.0	5.03	32.0	5.81	24.0
	3	3.86	0	4.51	9.6	4.54	13.6	5.03	12.0
	4	3.79	0	3.73	0	3.79	0	4.05	0
	5	3.79	0	3.73	0	3.73	0	3.92	0
NK	1	3.89	84.0	4.57	62.4	6.00	54.4	6.32	78.4
	2	3.86	16.0	4.44	24.0	5.90	26.4	6.00	13.6
	3	3.79	0	4.38	13.6	5.84	19.2	5.35	8.0
	4	3.73	0	4.05	0	4.03	0	4.18	0
	5	3.73	0	3.89	0	3.89	0	4.05	0
NP	1	3.92	88.0	4.54	72.0	4.54	70.4	5.42	80.0
	2	3.89	12.0	4.54	17.6	4.57	16.0	5.68	14.4
	3	3.83	0	4.22	10.4	4.48	8.0	5.35	5.6
	4	3.79	0	3.89	0	4.38	5.6	4.22	0
	5	3.79	0	3.73	0	3.73	0	4.05	0
NPK	1	3.90	82.7	4.78	60.9	5.49	72.8	5.75	76.0
	2	3.95	13.5	4.59	21.3	5.22	14.4	5.63	14.0
	3	3.88	3.8	4.66	16.3	4.95	10.7	5.03	9.4
	4	3.76	0	4.27	1.5	4.18	2.0	4.67	0.6
	5	3.77	0	4.04	0	3.96	0	3.79	0

[a)] 1:0-5, 2:5-10, 3:10-15, 4:15-20, 5:20-25 cm.

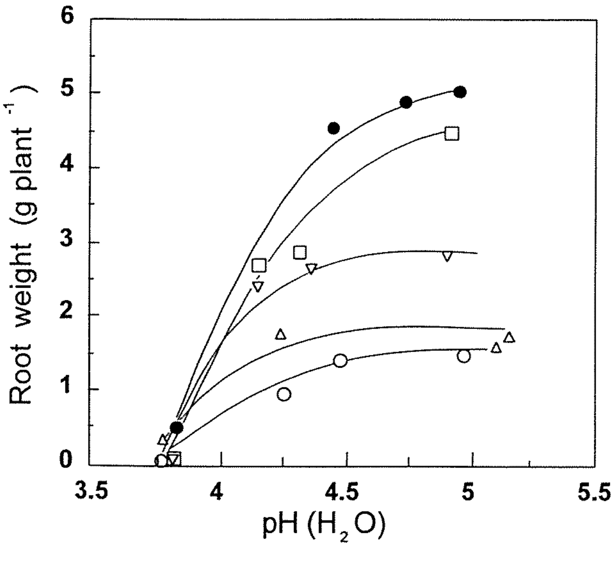

Fig. 3. Relationship between soil acidity (pH) and root weight of maize at 35 days after sowing (○:0, △:NK, ▽:PK, □:NP, ●:NPK)

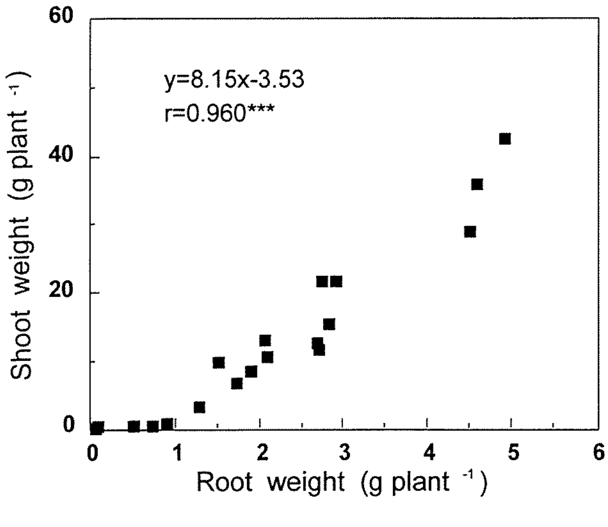

Fig. 4. Relationship between root weight and shoot weight of maize at 35 days after sowing (Statistical relationship was calculated using the data excluding L0 plot and X in the equation should be larger than 1.0)

susceptibility to the depletion of water and plant nutrients, hence enhancing the adverse effects of the soil acidity. This phenomenon can be attributed to the fact that charge imbalance and the pH gradient between root and soil which normally promote nutrient uptake were absent in a medium with a low pH[23].

In conclusion, based on the present field experiment it was suggested that better growth and/or higher grain yield of maize in acidic peat soil could be obtained by the amendment of soil pH in deeper layers to enable maize roots to grow in a larger rhizosphere volume. From the viewpoint of sustainable agriculture, however, application rate and depth of liming should be limited as much as proper maize growth permits it, since the loss of peat soil organic matter by decomposition in soils with a higher pH value and/or higher ash content has been known to be greater than in soils of adverse properties[19, 20].

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熱帯泥炭土壌における酸性矯正及び施肥処理がトウモロコシの根の生育に及ぼす影響

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摘　要

熱帯泥炭土壌は作物養分に乏しく，強酸性であるためにその農業利用にあたって，土壌の酸性矯正や施肥に関する多くの研究がなされてきたが，そのほとんどは地上部の生育あるいは収量との関係で解析されており，根の生育についてはほとんどなされていない。そこで，本研究ではマレイシア農業開発研究所ジャランケブン試験場において，泥炭土壌における酸性の矯正および三要素施肥がトウモロコシ，特にその根の生育にどのように影響するかを，酸性矯正レベルを４段階（0，12.5，25.0，50.0t ha^{-1}苦土石灰）とし，それぞれに三要素施肥処理区（0，NK，PK，NP，NPK）を設けて検討した。

トウモロコシは土壌の酸性矯正なしではNPKを施用しても貧弱な生育しか示さず，雄穂出穂前に枯死した。トウモロコシの根は石灰施用区では，54％以上，石灰無施用区では83％以上が表層５cmに分布した。また，苦土石灰による酸性矯正が及ばないpH3.8以下の下層には根の伸長が見られず，土壌酸性によって根の生育が阻害されたと考えられた。土壌の酸性矯正により根の生育及び地上部の生育は共に促進された。さらに，根の生育に対する三要素肥料の効果は，特にＮとＰで顕著であった。播種後35日に測定した根重と地上部重には高い正の相関関係が認められた。トウモロコシ子実（生鮮食用）の最高収量は苦土石灰25t ha^{-1}とNPK併用区で得られ，過剰の石灰施用は収量増加に寄与しなかった。

以上のことから，熱帯泥炭土壌での作物の適正生育には土壌の酸性矯正と施肥が必須であるが，さらに増収を目指すためには，根域の拡大，すなわち，酸性矯正の深さを大きくすることが有効となることが示唆された。しかしながら，石灰施用は泥炭有機物の分解を促進することが知られており，酸性矯正の程度と深さは，土壌保全あるいは持続的農業利用の視点からも考慮されなければならない。

キーワード：酸性土壌，石灰施用，根生育，熱帯農業

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