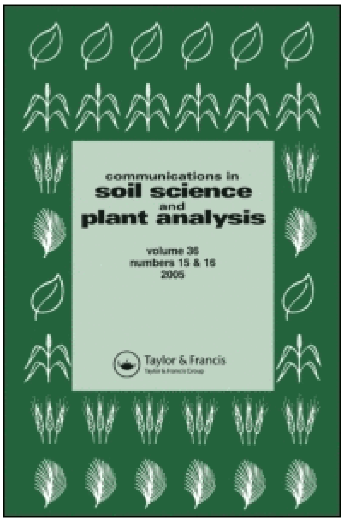

Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597241

Differential Soil Acidity Tolerance of Tropical Legume Cover Crops

N. K. Fageria [a]; V. C. Baligar [b]; Y. C. Li [c]
[a] National Rice and Bean Research Center of EMBRAPA, Santo Antônio de Goiás, Brazil [b] Perennial Crops Research Laboratory, Beltsville Agricultural Research Center, U.S. Department of Agriculture-Agriculture Research Service, Beltsville, Maryland, USA [c] Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, Homestead, Florida, USA

Online Publication Date: 01 April 2009

To cite this Article Fageria, N. K., Baligar, V. C. and Li, Y. C.(2009)'Differential Soil Acidity Tolerance of Tropical Legume Cover Crops',Communications in Soil Science and Plant Analysis,40:7,1148 — 1160

To link to this Article: DOI: 10.1080/00103620902754127

URL: http://dx.doi.org/10.1080/00103620902754127

Communications in Soil Science and Plant Analysis, 40: 1148–1160, 2009

ISSN 0010-3624 print/1532-2416 online
DOI: 10.1080/00103620902754127

Differential Soil Acidity Tolerance of Tropical Legume Cover Crops

N. K. Fageria,[1] V. C. Baligar,[2] and Y. C. Li[3]

[1]National Rice and Bean Research Center of EMBRAPA, Santo Antônio de Goiás, Brazil
[2]Perennial Crops Research Laboratory, Beltsville Agricultural Research Center, U.S. Department of Agriculture–Agriculture Research Service, Beltsville, Maryland, USA
[3]Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, Homestead, Florida, USA

Abstract: In tropical regions, soil acidity and low soil fertility are the most important yield-limiting factors for sustainable crop production. Using legume cover crops as mulch is an important strategy not only to protect the soil loss from erosion but also to ameliorate soil fertility. Information is limited regarding tolerances of tropical legume cover crops to acid soils. A greenhouse experiment was conducted to determine the differential tolerance of 14 tropical legume cover crops to soil acidity. The acidity treatments were high (0 g lime kg^{-1} soil), medium (3.3 g lime kg^{-1} soil), and low (8.3 g lime kg^{-1} soil). Shoot dry weight of cover crops were significantly affected by acidity treatments. Maximum shoot dry weight was produced at high acidity. Jack bean, black mucuna, and gray mucuna bean species were most tolerant to soil acidity, whereas Brazilian lucern and tropical kudzu were most susceptible to soil acidity. Overall, optimal soil acidity indices were pH 5.5, hydrogen (H)+ aluminum (Al) 6.8 $cmol_c$ kg^{-1}, base saturation 25%, and acidity saturation 74.7%. Species with higher seed weight had higher tolerance to soil acidity than those with lower seed weight. Hence, seed weight was associated with acidity tolerance in tropical legume species.

Keywords: Base saturation, Oxisol, shoot dry weight, soil pH

Received 2 July 2007, Accepted 8 September 2007
Address correspondence to N. K. Fageria, National Rice and Bean Research Center of EMBRAPA, Caixa Postal 179, Santo Antônio de Goiás, GO, CEP 75375-000, Brazil. E-mail: fageria@cnpaf.embrapa.br

INTRODUCTION

Invariably, plantation crops such as cacao, coffee, and oil palm are planted on sloped land, with wide spacing. In early stages of plantation crops, soil is unprotected and subjected to loss by erosion. Weed infestation is also a serious problem in early growth stages of plantation crops. Fast-growing cover crops in early plantation establishment could help to reduce soil loss by erosion and improve soil organic-matter buildup (Cunningham and Smith 1961; Wood and Lass 2001). Use of legume cover crops is one of the practices that can reduce soil erosion, control weeds, and improve soil fertility (Fageria, Baligar, and Bailey 2005).

Soil acidity and low fertility are the major constraints for good growth of legume cover crops in tropical plantation crops. In tropical South America, 85% of the soils are acidic, and approximately 850 million ha of this area are underutilized (Fageria and Baligar 2003). Theoretically, soil acidity is measured in terms of hydrogen (H^+) and aluminum (Al^{3+}) ion concentrations in soil solution. However, under practical conditions of crop production, soil acidity involves many factors that adversely affect plant growth and development. At pH less than 5.0, toxic levels of Al, H, and sometimes manganese (Mn), as well as deficiencies of many macro- and micronutrients, may reduce plant growth on acidic soils. In addition, beneficial activities of some microorganism species are reduced by soil acidity (Fageria and Baligar 2003). Legume cover crops with greater tolerance to soil acidity and low fertility offer considerable promise for establishing vegetative cover and eventually increasing soil fertility and productivity of marginal lands under tropical plantation crops. Limited numbers of legume crops have been tested for their suitability as cover crops in plantation crops such as cacao (Jorden and Opoku 1966; Wilson 1999; Wood and Lass 2001). However, a large number of tropical legume crops exists, but their ability to tolerate soil acidity under plantation crops is not known. Many of the cover crop legumes known to have wide range of tolerance to soil acidity (pH 4.5–8.0) and calopo (*Calapogonium mucunoides*), centro (*Centosema macrocarpum*), cowpea (*Vigna unguiculata*), ea-ea (*Desmodium heterocarpon*), joint vetch (*Aeschynomene Americana* L.), perennial peanut (*Arachis pintoi*), Brazilian lucern (*Stylosanthes guianensis*), the stylos (*Stylosanthes* spp.), and white tephrosia (*Tephrosia candida*) are good cover crops, are known to grow in acidic infertile soils of pH 4.5 to 8.0, and have high tolerance to toxic levels of soil Al (Skerman, Cameron, and Riveros 1988; Van der Maesen and Somaatmadja 1989; Lewis et al. 2005). Liming significantly increased the dry-matter production of tropical kudzu in acidic soil of pH 5.0 (Philip et al. 1995). Caravalho et al. (1985) reported that in Oxisols of Brazil, butterfly pea (*Cenrosema pubscens*) responded well to added calcium (Ca) and magnesium (Mg).

Available information on ability of tropical legume cover crops to tolerate acidic soil complexes and low fertility is rather limited. The objective of this study was to evaluate a range of differential tolerance of 14 tropical legume cover crops for soil acidity.

MATERIALS AND METHODS

Soil Properties and Level of Soil Acidity

The soil used in the experiment was an Oxisol with the following chemical and physical properties before imposing acidity treatments: pH in H_2O 5.1, Ca 1.3 $cmol_c\,kg^{-1}$, Mg 0.6 $cmol_c\,kg^{-1}$, Al 0.3 $cmol_c\,kg^{-1}$, phosphorus (P) 0.6 $mg\,kg^{-1}$, potassium (K) 51 $mg\,kg^{-1}$, copper (Cu) 1.7 $mg\,kg^{-1}$, zinc (Zn) 0.7 $mg\,kg^{-1}$, iron (Fe) 59 $mg\,kg^{-1}$, manganese (Mn) 14 $mg\,kg^{-1}$, organic matter 22 $g\,kg^{-1}$, clay 643 $g\,kg^{-1}$, silt 100 $g\,kg^{-1}$, and sand 257 $g\,kg^{-1}$. Soil analytical methodology used is described in the manual of soil analysis (EMBRAPA 1997). The acidity treatments were created by applying dolomitic lime at the rate of 0 $g\,kg^{-1}$ (high acidity), 3.3 $g\,kg^{-1}$ (medium acidity), and 8.3 $g\,kg^{-1}$ of soil (low acidity). The liming material used had 32.9% calcium oxide (CaO), 14.0% magnesium oxide (MgO), and neutralizing power of 85%. The lime rates were applied 4 weeks before sowing the cover crops, and pots were subjected to dry and wet cycling. At the time of sowing, basal fertilizer rates used were 200 mg N kg^{-1} of soil, 200 mg P kg^{-1} of soil, and 200 mg K kg^{-1} of soil. Nitrogen was applied as urea, P was applied as triple superphosphate, and K was applied as potassium chloride.

Cover Crop Species

Fourteen tropical cover crop legumes were evaluated in this study, and common and scientific names of these cover crops are given in Table 1. These include short-flowered crotalaria, sunnhemp, smooth crotalaria, showy crotalaria, crotalaria, calapo, pigeonpea, lablab, mucuna bean ana, black mucuna bean, gray mucuna bean, jack bean, tropical kudzu, and Brazilian lucerne. Seeds were received from various sources: seeds of calapo, tropical kadzu, and Brazilian lucern were received from Globo Rural Seed Company (Goania, GO, Brazil[1]), and seeds of other

[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

Table 1. Common and scientific names and 100-seed weights of legume species used in the experiment

Common name	Scientific name	100-seed weight (g)
Short-flowered crotalaria	*Crotalaria breviflora* DC.	1.87
Sunnhemp	*Crotalaria juncea L.*	5.07
Smooth crotalaria	*Crotalaria pallida* Aiton/*Crotalaria mucronata* Desv.	0.61
Showy crotalaria	*Crotalaria spectabilis* Roth	1.55
Crotalaria	*Crotalaria ochroleuca* G. Don	0.65
Calapo	*Calapogonium mucunoides*	1.39
Pigeonpea	*Cajanus cajan* L. Millspaugh	12.05
Lablab	*Dolichos lablab* L.	23.44
Mucuna bean ana	*Mucuna pruriens L./Mucuna deeringiana* (Bort) Merr.	54.78
Black mucuna bean	*Mucuna pruriens/Mucuna aterrima* (Piper & Tracy) Holland	76.31
Gray mucuna bean	*Mucuna cinereum* L.	98.77
Jack bean	*Canavalia ensiformis* L. DC.	132.20
Tropical kudzu	*Pueraria phaseoloides* (Roxb).	12.00
Brazilian lucerne	*Stylosanthes guianensis* (Aubl.) Sw.	0.27

remaining legume cover crops were received from Pirai Seed Company (Piracicaba, SP, Brazil).

Growth Conditions

A greenhouse experiment was conducted at the National Rice and Bean Research Center of EMBRAPA (Santo Antônio de Goiás, GO, Brazil) to determine acidity tolerance of 14 tropical legume cover crops. The experiment was planted on 5 September 2005 and harvested on 21 October 2005. Mean monthly maximum temperature was 32 °C, and minimum temperature was 18.8 °C during the month of September. During the month of October, these values were 33.8 and 20.5 °C, respectively. Mean relative humidity was 24.7% in the month of September 2005 and 26.1% during the month of October 2005. The experiment was conducted in plastic pots with 7 kg soil in each pot. High-quality cover crop seeds were used for planting. After germination, four plants were maintained in each pot. Plants were grown at field capacity, and every day desired amount of water was added to keep the moisture level. Plants were harvested at 46 days after sowing. Harvested material was washed in distilled water several times and dried in an oven at 70 °C to a constant weight to determine biomass accumulations.

Observations and Data Analysis

Shoot dry-weight efficiency index (SDWEI) was calculated to classify legume species for their differential tolerance to soil acidity by using following equation:

$$\begin{aligned}\text{SDWEI} = {} & (\text{shoot dry weight at medium or low acidity level/average} \\ & \text{shoot dry weight of 14 species at medium or low acidity level)} \\ & \times (\text{shoot dry weight at high acidity level/average shoot dry} \\ & \text{weight of 14 species at high acidity level)}\end{aligned}$$

Species having SDWEI values >1 were classified as tolerant, species having SDWEI values between 0.5 and 1 were classified as moderately tolerant, and those with SDWEI values <0.5 were classified as susceptible to soil acidity. These acidity tolerance ratings were selected arbitrarily. Soil samples were taken at harvest for four acid tolerant (pigeonpea, lablab, black mucuna bean, and jack bean) and two susceptible legume species (short-flowered crotalaria and Brazilian lucern) from each pot to determine chemical properties.

Analysis of variance was used to evaluate treatment effects, and means were compared by Turkey's test at the 5% probability level. Regression analysis was also done wherever it was necessary. Appropriate regression model was selected on the basis of R^2.

RESULTS AND DISCUSSION

Shoot dry weight was significantly affected by soil acidity treatment, legume species, and interactions (Table 2). At high soil acidity, shoot dry weight varied from 3.76 to 21.43 g, with an average value of 10 g. Similarly, at the medium soil acidity level, shoot dry weight varied from 0.32 to 19.78 g with an average value of 7.09 g. At the low soil acidity level, shoot dry-weight values varied from 0.18 to 13.52 g, with an average value of 3.95 g. At medium and low acidity levels, the decreases in shoot dry weight were 41 and 153%, respectively, compared with high soil acidity. Overall weights of legume species at all lime treatments varied from 1.48 g per plant for Brazilian lucern to 18.24 g per plant for Jack bean.

The variation in shoot dry weight at lower, medium, and high acidity indicates that the 14 legume species differed in their response to the level of soil acidity. Inter- and intraspecific differences in plant dry-matter yields due to soil acidity/Al toxicity in temperate legumes have been reported (Andrew, Johnson, and Sandland 1973; Baligar and Fageria

Table 2. Shoot dry weight (g plant^{-1}) of 14 tropical legume cover crops at three acidity levels

Legume species	High acidity	Medium acidity	Low acidity	Average
Short-flowered crotalaria	4.04d	1.97fg	0.91	2.31gh
Sunnhemp	12.32bc	7.76cde	4.23bc	8.10cdef
Smooth crotalaria	4.24d	2.87efg	1.41cd	2.84gh
Showy crotalaria	5.80d	4.35defg	3.74bcd	4.63fgh
Crotalaria	13.05bc	6.12cdef	3.44bcd	7.53def
Calapo	4.88d	3.11defg	1.82cd	3.27gh
Pigeonpea	7.80cd	5.45cdefg	4.09bc	5.78efg
Lablab	14.31b	10.39bc	5.80b	10.17bcd
Mucuna bean ana	12.99bc	8.39bcd	4.32bc	8.57cde
Black mucuna bean	16.39ab	13.46b	6.48b	12.11b
Gray mucuna bean	15.13b	13.79b	4.47bc	11.13bc
Jack bean	21.43a	19.78a	13.52a	18.24a
Tropical kudzu	3.76d	1.61fg	0.92cd	2.09h
Brazilian lucerne	3.95d	0.32g	0.18d	1.48h
Average	10.00	7.09	3.95	6.69
F-test				
Soil acidity (S)		**		
Legume species (L)		**		
S × L		**		

**Significant at the 1% probability level.

Note. Means followed by the same letter in the same column are not significantly different by Tukey's test at the 5% probability level.

1997). However, published information regarding the acidic soil tolerance of the tropical legume species used in this study is limited. Hence, it is not possible to compare results obtained here with published information. However, Garvin and Carver (2003) reported that genetic variation allows different plant species and different cultivars of the same species to exhibit differing abilities to grow in acidic soils. Similarly, Devine, Bouton, and Mabrahtu (1990) reported that variability for tolerance to acidic soils has been documented both among and within germplasm of legume species. Kamprath (1984) also reported that many tropical forage legumes are rather tolerant to low soil pH except where high levels of Mn are present. Tropical legumes have shown a positive response to low concentration of Al in soil (Andrew, Johnson, and Sandland 1973), and such beneficial effects of Al have been observed in several other crops (Foy 1984). It has also been observed that many tropical legumes known to tolerate soil pH as low as 4.5 (Skerman, Cameron, and Riveros 1988; Van der Maesen and Somaatmadja 1989; Lewis et al. 2005). Growth improvement of tropical kadzu (Philip et al. 1995) and butterfly pea (Carvalho et al. 1985) in acidic soils with addition of lime has been reported.

Legume species were classified according to soil acidity tolerance on the basis of shoot dry-weight efficiency index (SDWEI) (Table 3). The SDWEI was significantly and positively correlated with shoot dry weight (Figure 1). Ninety-seven percent variation in shoot dry weight was associated with variation in SDWEI. This means that this index is efficient in rating tolerance of legume crop species to soil acidity. At the medium acidity level, 7 of the 14 crop species fell into the tolerant growth, which included jack bean, black mucuna bean, gray mucuna bean, lablab, sunnhemp, and *Crotalaria ochroleuca*. The species calapo and pigeonpea were moderately tolerant. Five species (i.e., short-flowered crotalaria, smooth crotalaria, tropical kudzu, showy crotalaria, and Brazilian lucern) were classified as susceptible. At the low acidity level, similar ratings were obtained, except calapo dropped from moderately tolerant at medium soil acidity to susceptible at the low acidity level. Similarly, showy crotalaria was susceptible at medium acidity level and classified as moderately tolerant at low acidity level (Table 3).

The overall decrease in shoot dry weights of several species with decreasing acidity indicates that legume species evaluated were tolerant to soil acidity. The acidic soil tolerance of these may be because they were selected and bred under Brazilian acidic soil conditions. For example, several studies have revealed that variation for Al tolerance among wheat cultivars is correlated with their origin (Foy et al. 1974; Garvin and Carver 2003).

Table 3. Shoot dry-weight efficiency index (SDWEI) of legume species at medium and low soil acidity level and their classification according to soil acidity tolerance

Legume species	SDWEI at medium acidity[a]	SDWEI at low acidity
Short-flowered crotalaria	0.14S	0.11S
Sunnhemp	1.62T	1.50T
Smooth crotalaria	0.21S	0.22S
Showy crotalaria	0.43S	0.66MT
Crotalaria	1.35T	1.36T
Calapo	0.56MT	0.27S
Pigeonpea	0.73MT	0.98MT
Lablab	2.49T	2.47T
Mucuna bean ana	1.94T	1.66T
Black mucuna bean	3.76T	3.22T
Gray mucuna bean	3.60T	2.04T
Jack bean	7.15T	8.80T
Tropical kudzu	0.09S	0.11S
Brazilian lucerne	0.03S	0.02S

[a]T = tolerant, MT = moderately tolerant, and S = susceptible.

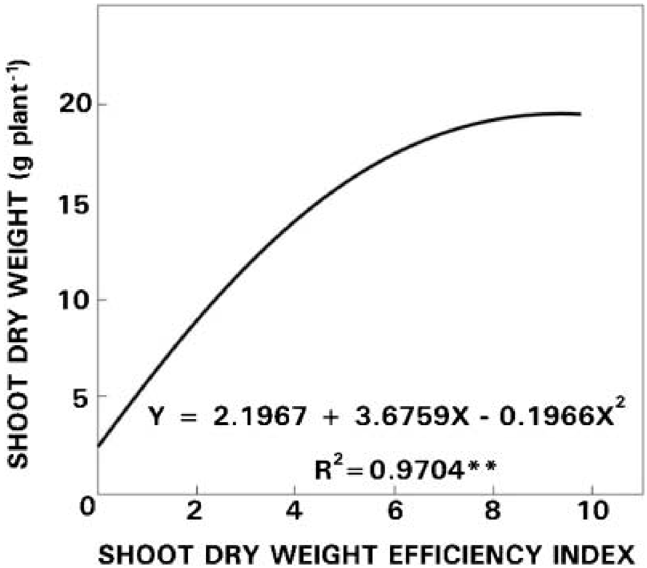

Figure 1. Relationship between shoot dry-weight efficiency index and shoot dry weight. Values are across legume crop species and acidity levels.

Anather striking feature of our study was the importance of seed size. Seed weight was positively and significantly correlated with SDWEI (Figure 2). Variation in SDWEI was 86% associated with variation in seed weight. Species like jack bean, gray mucuna bean, black mucuna bean, mucuna bean, and lablab have higher seed weights (Table 1) and higher acidity tolerance (Table 3). Similarly, Brazilian lucern, tropical kudzu, and short-flowered crotalaria had lowest seed weight (Table 1) and were susceptible to soil acidity. Devine, Bouton, and Mabrahtu (1990) reported that seed weight of soybean was positively related to Al tolerance.

Analysis of variance showed significant effects of acidity treatment on soil chemical properties. However, there was no significant effect of legume species and acidity level × legume species interaction. Hence, only average data of acidity treatment are presented (Table 4). Values of pH, base saturation, and acidity saturation show that wide variation was created in acidity indices by liming to evaluate response of legume species to acidity. In addition, pH, Ca concentration, Mg concentration, Ca saturation, and Mg saturation increased with decreasing acidity, as expected. Similarly, H + Al concentration, Al concentration, and acidity saturation decreased with decreasing acidity. However, P and K concentrations were increased with decreasing acidity. The improvement of P with decreasing acidity may be associated with liberation of this element from Fe and Al hydroxides with increasing pH (Brady and Weil 2002). Similarly, the increase in K concentration may be associated with

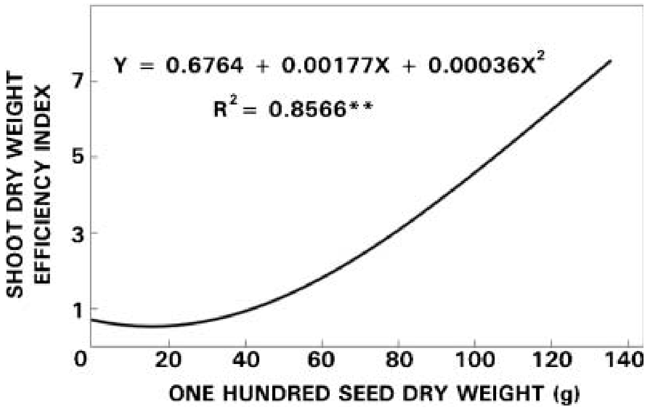

Figure 2. Relationship between seed dry weight and shoot dry-weight efficiency index. Values are across the legume crop species and acidity levels.

increasing Ca and Mg saturation; K might have been liberated from soil colloids in this pH range. Fageria (1984) reported increases in soil P and K with increasing pH from 5.1 to 6.5 in Brazilian Oxisols.

Table 4. Soil chemical properties under three acidity levels (values are across six legume species determined at harvest)

Chemical property	High acidity	Medium acidity	Low acidity
pH in H_2O	5.5c	6.5b	7.0a
Ca ($cmol_c\,kg^{-1}$)	1.4c	3.0b	4.0a
Mg ($cmol_c\,kg^{-1}$)	0.7b	1.4a	1.4a
Al ($cmol_c\,kg^{-1}$)	0.2	0	0
K ($cmol_c\,kg^{-1}$)	0.2b	0.3a	0.3a
P ($mg\,kg^{-1}$)	22.3b	31.7a	32.5a
H+AL ($cmol_c\,kg^{-1}$)	6.8a	3.2b	1.8c
CEC ($cmol_c\,kg^{-1}$)	9.1a	7.9b	7.5b
Base saturation (%)[a]	25.3c	59.2b	76.4a
Acid saturation (%)[b]	74.7a	40.8b	23.3c
Ca saturation (%)[c]	15.3c	38.0b	53.1a
Mg saturation (%)[d]	7.8b	17.8a	19.3a
Ca/Mg ratio	2.1b	2.1b	2.8a
Ca/K ratio	7.9b	12.6a	14.8a
Mg/K ratio	4.1b	6.0a	5.3ab

[a]Base saturation (%) = Σ(Ca, Mg, K) / (CEC) × 100, where CEC = Σ(Ca, Mg, K, H, Al) in $cmol_c\,kg^{-1}$.
[b]Acid saturation (%) = (H + Al) / CEC) × 100.
[c]Ca saturation (%) = (Ca / CEC) × 100.
[d]Mg saturation (%) = (Mg / CEC) × 100.
Note. Means followed by the same letter in the same line are not significantly different by Tukey's test at the 5% probability level.

All of the soil Al was neutralized at pH 6.5 and higher (Table 4). However, soil acidity saturation was 40.8% at medium and 23.3% at low acidity treatments. This means that in Oxisols, Al acidity is easily neutralized but H^+ ion acidity still remains as a potential factor at higher pH. Plant species and genotypes within species differ widely in tolerance to excess H^+; however, the direct effects of the H ion toxicity is difficult to assess because at low pH, potentially harmful Al and Mn may be present in toxic concentrations and availability of essential elements [particularly Ca, Mg, P, molybdenum (Mo), and silicon (Si)] may be suboptimal (Foy 1984). Foy (1984) further states that in most acidic soils (pH > 4.0), Al^{3+} and Mn^{2+} toxicities are probably more important than H^+ ion toxicity in limiting the growth of higher plants, particularly the nonlegumes. Plant growth decline at pH levels greater than 5 is attributed to reduced availability of metal micronutrients. At pH 4 and 5, Ca in nutrient solution substantially improves the root growth, and Ca decreases toxicity of H^+ in nutrient solution studies (Moore 1974).

Optimal values of soil acidity indices were determined on the basis of correlation between soil chemical properties and shoot dry weight (Table 5). Overall, a highly significant negative correlation was obtained with P, K, and Ca/Mg ratio. This means increasing P level more than 22.3 mg kg^{-1}, K level more than 0.2 $cmol_c\,kg^{-1}$, and Ca/Mg ratio more than 2.1 may create nutritional imbalance and decrease shoot dry weight.

Table 5. Correlation between shoot dry weights and soil chemical properties across three acidity levels

Soil property	Correlation (r) value	Optimal value[a]
PH in H_2O	-0.19^{NS}	5.5
Ca ($cmol_c\,kg^{-1}$)	-0.26^{NS}	1.4
Mg ($cmol_c\,kg^{-1}$)	-0.10^{NS}	0.7
P ($mg\,kg^{-1}$)	-0.43^{**}	22.3
K ($cmol_c\,kg^{-1}$)	-0.45^{**}	0.2
H+AL ($cmol_c\,kg^{-1}$)	$+0.23^{NS}$	6.8
CEC ($cmol_c\,kg^{-1}$)	$+0.17^{NS}$	9.1
Base saturation (%)	-0.24^{NS}	25.3
Acidity saturation (%)	$+0.24^{NS}$	74.7
Ca saturation (%)	-0.26^{NS}	15.3
Mg saturation (%)	-0.10^{NS}	7.8
Ca/Mg ratio	-0.43^{**}	2.1
Ca/K ratio	-0.27^{NS}	7.9
Mg/K ratio	$+0.50^{**}$	5.3

**, ^{NS}Significant at the 1% probability level and nonsignificant, respectively.

[a]Where r values were nonsignificant or significantly negative, optimal values were those at the high acidity level in Table 4. In the case of significantly positive, optimal values are those at the low acidity level in Table 4.

Data about soil acidity indices for tropical legume crops in Brazilian Oxisols are not available in the literature; hence results of this study cannot be compared with published information. However, nonsignificant correlations with most of the other soil properties indicate that these legume crop species can be grown without significant decrease in yield in a wide range of pH levels (more than 5.5), acidity saturation, and base saturation. Based on these results, it can be concluded that adequate lime rate can be applied for planting these legume species in rotation with cash legume crops such as dry bean and soybean, which require greater pH values(6.6–6.8) and base saturation (66–69%) when grown on Brazilian Oxisols (Fageria 2001; Fageria and Stone 2004). For plantation crop such as cacao, where soil acidity is in the range of pH 4 to 5.5, these legume crops have advantages in establishing and protecting the soil from erosion losses and eventually improving soil organic-matter content and fertility.

CONCLUSIONS

Tropical legume species showed different tolerances to soil acidity. However, all 14 species grow well under high acidity levels (overall, pH 5.5, H + Al 6.8 $cmol_c\,kg^{-1}$, and base saturation of 25%). The SDWEI was significantly and positively correlated with shoot dry weight and can be used as an index for rating legume crop species' tolerance to soil acidity. Based on SDWEI, most acidity-tolerant species in increasing order were jack bean > black mucuna bean > gray mucuna bean > lablab > mucuna bean ana > sunnhemp > crotalaria. The most susceptible species were Brazilian lucern > tropical kudzu > short-flowered crotalaria > smooth crotalaria. Seed weight is associated with acidity tolerance, and higher seed reserve seems to contribute to the acidity tolerance. Because adequate N was supplied as fertilizer, the role of rhizobium in these results is unknown.

ACKNOWLEDGMENTS

We thank Dr. C. D. Foy for his valuable comments and suggestions on improving the manuscript.

REFERENCES

Andrew, C. S., A. D. Johnson, and R. L. Sandland. 1973. Effects of aluminium on growth and chemical composition of some tropical and temperate pasture legumes. *Australian Journal of Agricultural Research* 24:325–339.

Baligar, V. C., and N. K. Fageria. 1997. Nutrient use efficiency in acid soils: Nutrient management and plant use efficiency. In *Plant–soil interactions at low pH: Sustainable agriculture and forestry production*, ed. A. C. Moniz, A. M. C. Furlani, N. K. Fageria, C. A. Rosolem, and H. Cantarells, 75–95. Campinas, Brazil: Brazilian Soil Science Society.

Brady, N. C., and R. R. Weil. 2002. *The nature and properties of soils*, 13th ed. Upper Saddle River, N.J.: Prentice Hall.

Carvalho, M. M., F. T. Oliveira, O. F. Saraiva, and C. E. Martins. 1985. Nutritional factors limiting growth of tropical forage species in two soils from "Zona da Mata" Minas Gerais, Brazil I: Red-yellow latosol. *Pesquisa Agropecuaria Brasileira* 20:519–528.

Cunningham, R. K., and R. W. Smith. 1961. Comparison of soil covers during cocoa establishment on clear-felled land. *Tropical Agricultural Transaction* 38:13–22.

Devine, T. E., J. H. Bouton, and T. Mabrahtu. 1990. Legume genetics and breeding for stress tolerance and nutrient efficiency. In *Crops as enhancers of nutrient use*, ed. V. C. Baligar and R. R. Duncan, 211–252. New York: Academic Press.

EMBRAPA. 1997. *Manual of soil analysis methods*, 2nd ed. Rio de Janeiro, Brazil: National Research Center of Soils.

Fageria, N. K. 1984. Response of rice cultivars to liming in cerrado soil. *Pesquisa Agropecuaria Brasileira* 19:883–889.

Fageria, N. K. 2001. Response of upland rice, dry bean, corn, and soybean to base saturation in cerrado soil. *Revista Brasileira de Engenharia Agrícola e Ambiental* 5:416–424.

Fageria, N. K., and V. C. Baligar. 2003. Fertility management of tropical acid soils for sustainable crop production. In *Handbook of soil acidity*, ed. Z. Rengel, 359–385. New York: Marcel Dekker.

Fageria, N. K., V. C. Baligar, and B. A. Bailey. 2005. Role of cover crops in improving soil and row crop productivity. *Communications in Soil Science and Plant Analysis* 36:2733–2757.

Fageria, N. K., and L. F. Stone. 2004. Yield of common bean in no-tillage system with application of lime and zinc. *Pesquisa Agropecuaria Brasileira* 39:73–78.

Foy, C. D. 1984. Physilogical effects of hydrogen, aluminum, and manganese toxicities in acid soil. In *Soil acidity and liming*, 2nd ed., ed. F. Adams, 57–97. Madison, Wisc.: ASA, CSSA, and SSSA.

Foy, C. D., H. N. Lafever, J. W. Schwartz, and A. L. Fleming. 1974. Aluminum tolerance of wheat cultivars related to region of origin. *Agronomy Journal* 66:751–758.

Garvin, D., and B. F. Carver. 2003. Role of the genotypes in tolerance to acidity and aluminum toxicity. In *Handbook of soil acidity*, ed. Z. Rengel, 387–406. New York: Marcel Dekker.

Jorden, D., and A. A. Opoku. 1966. The effect of selected soil covers on the establishment of cacao. *Tropical Agriculture Transations* 43:155–166.

Kamprath, E. J. 1984. Crop response to lime on soils in the tropics. In *Soil acidity and liming*, 2nd ed., ed. F. Adams, 349–368. Madison, Wisc.: ASA, CSSA, and SSSA.

Lewis, G., B. Schrire, B. Mackinder, and M. Lock. 2005. *Legumes of the world.* Richmond, Surrey, UK: Kew Publishing.

Moore, D. P. 1974. Physiological effects of pH on roots. In *The plant roots and its environment*, ed. E. W. Carson, 135–151. Charlottesville: University Press of Virginia.

Philip, A. M., Joseph, K. I. Punnoose, and A. P. Antony. 1995. Effects of liming on nutrient uptake, biomass production, and nodulation in *Pueraria phaseoloides*. *Indian Journal of Natural Rubber Research* 8:130–134.

Skerman, P. J., D. G. Cameron, and F. Riveros, ed. 1988. *Tropical forage legumes*. Rome, Italy: FAO, United Nations.

Van der Maesen, L. J. G., and S. Somaatmadja. 1989. *Plant resources of southeast Asia*, vol. 1, ed. L. J. G. Van der Maesen and S. Somaatmadja, 15–32. Wageningen, the Netherlands: Pudoc.

Wilson, K. 1999. *Coffee, cocoa, and tea*. Oxon, UK: CABI Publishing.

Wood, G. A. R., and R. A. Lass. 2001. *Cocoa,* 4th ed. Oxford, UK: Blackwell Science.