Research paper

Growth and dry matter partitioning of common bean (*Phaseolus vulgaris*, L) genotypes as influenced by aluminum toxicity

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ABSTRACT

Aims: *This study was carried out to assess the effects of different concentrations of exchangeable aluminium on growth and dry matter partitioning of two common bean genotypes grown on lime-treated and lime-untreated acid soils.*

Design: *Factorial combinations of five rates of aluminium (0, 12.5, 25, 50, and 100 mg Al kg soil^{-1}) and two common bean genotypes (New BILFA 58 and Roba 1) were laid out in a completely randomized design with three replications per treatment.*

Place and Duration of Study*: The experiment was conducted in the vegetation hall of Nekemte Soil Laboratory, western Ethiopia from July-October, 2011.*

Methodology: *For each treatment, four plants were raised per pot, data related to growth and dry matter partitioning of the crop were collected 25 and 35 days after seedling emergence (DAE).*

Result: *Application of aluminium had a significant adverse effect on growth and dry matter partitioning of both genotypes. Aluminium rate and genotype interacted to significantly (P=0.01) affect all parameters considered except Relative Growth Rate (RGR) and shoot to root weight ratio for the lime-untreated soil, and specific leaf area (SLA), leaf fraction as well as leaf area for the lime-treated soil. Compared to the lime-treated soil, significant reduction in growth was found for plants grown on the lime-untreated soil, particularly as the rate of aluminium applied was increased. On average, application of aluminium led to 37.5, 32.9, and 35.7% reduction in absolute growth rate (AGR), relative growth rate (RGR) and net assimilation rate (NAR) of the two genotypes. The differences due to the aluminium rate and genotype were also significant for dry matter partitioning and root to shoot ratio. On both lime-treated and lime-untreated soils, dry matter partitioning to the root was higher for new BILFA 58 than for Roba 1 at 25 and 35 DAE.*

Conclusion: *It could, thus, be concluded that applying aluminium significantly decreased growth of the two common bean genotypes under both lime-treated and lime-untreated soils. However, the growth reductions suffered by both genotypes were lower on the lime-treated soil than on the lime-untreated soil. In addition, the genotype new BILFA 58 performed better than the other genotype under increased soil acidity and aluminium concentration.*

Key words: Aluminum toxicity, Dry matter partitioning, Genotypes, Growth parameters, Lime

INTRODUCTION

Aluminium (Al) toxicity is recognized as a major constraint to crop productivity in acidic soils (1). It limits plant growth, development, and the subsequent performance of economically important crops in various parts of the world [2]. Al inhibits the absorption of nutrients, especially Ca, Mg, Fe and Mo and availability of P [3]in addition to promoting Mn and H^+ toxicity [2].

A range of environmental factors such as low availability of nitrogen (N) and phosphorus (P) in the soil, and acid soil conditions are important constraints to common bean production in most areas where the crop is grown [4]. Patterns of dry matter diversion and root plasticity are considered as important features influencing the ability of grain legume crops to cope with soil acidity. Growth analysis technique has made substantial contributions to the current understanding of the physiological basis of yield differences in crops. Leaf area index [LAI], specific leaf area (SLA), leaf area ratio (LAR), net assimilation rate (NAR), absolute growth rate (AGR), relative growth rate (RGR), and indices of dry matter partitioning are some of the parameters which are often used to compare growth of plants or cultivars of different genetic background when grown across a range of environmental conditions [5].

Developing a strategy to enhance common bean performance on soils with high Al levels requires prior understanding of the physiological responses of genotypes with distinct genetic background. Good progress in this field has been made during the last few decades, and competent compilations

and critical reviews on several aspects of this field have been published, e.g. by Ma *et al*. [6]; Ryan *et al*. [7], and Barceló and Poschenrieder [8]. Most of the mechanisms studied are related to limited root growth and development or their consequences. Comparatively, less information exists about the effects of Al^{3+} on leaves than on roots (9). Hence, it is suggested that more attention should be paid to aerial tissues in future studies, which are important in revealing Al toxicity and mechanisms of plant tolerance to Al stress [10].

A preliminary field screening of common bean genotypes in western Ethiopia has demonstrated the presence of genetic variability among genotypes. Studying responses of selected genotypes with contrasting tolerance to aluminium toxicity may help in generating information that could be utilized by breeding programmes aimed at developing aluminium-tolerant cultivars for areas where aluminium-induced soil acidity remains the key environmental constraint. The objective of this study was to test the hypothesis that differences exist in growth, dry matter partitioning, and root to shoot ratio among common bean genotypes selected for soil acidity tolerance when subjected to different rates of aluminum applied on lime-treated and lime-untreated soil.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The experiment was conducted at Nekemte soil laboratory in western Ethiopia. The experimental site is located at 9^0 08' N latitude and $36^0$46' E longitude at the altitude of 2080 metres above sea level. According to the weather data recorded at the Nekemte Meteorological Station, the average annual rainfall of the study site is 1300 mm with 725 mm for the experimental period (July – October) and the monthly mean minimum and maximum temperatures were between 10-15^{o}C and 24 to 28 ^{0}C (Figure 1). The soil used for the pot experiment has a pH (H_2O) value of 4.81, exchangeable acidity of 4.92 cmol/kg soil, exchangeable Al of 3.1 cmol/kg soils, and acid saturation of 53.3 % before applying the treatments.

2.2. Description of Planting Materials

Screening experiments were conducted in 2009 and 2010 in the field at the soil pH of 4.45 and in pots at the pH of 4.8, respectively. Common bean genotypes named new BILFA 58 (NB 58) and Roba1 were identified as the most tolerant and sensitive genotypes to soil acidity, respectively. New BILFA 58 is a genotype with type III growth habit and large-sized seed (53 g per 100 seed) whereas Roba 1 is a small-seeded (22 g per 100 seed) commercial cultivar in Ethiopia with type II growth habit.

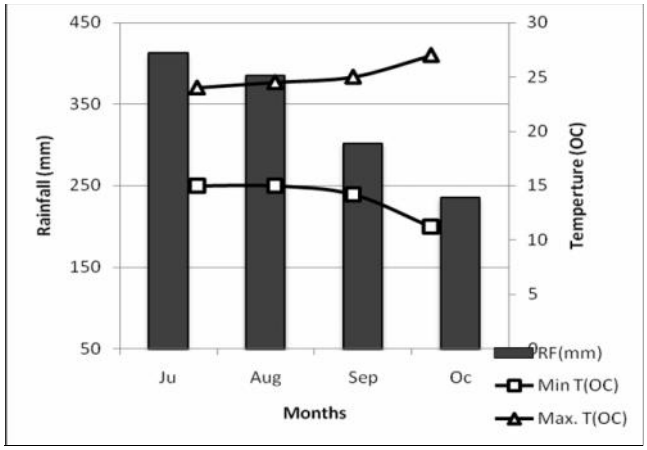

Figure 1. Rainfall distribution and mean minimum and maximum temperature of the experimental site, during the experimental period (2011), Nekemte, Ethiopia

2.3. Treatments and Experimental Design

The treatments consisted of two common bean genotypes (new BILFA 58 and Roba 1) and five rates of aluminium (0, 12.5, 25.0, 50.0, and 100.0 mg Al/kg soil). The experiment was laid in a completely randomized design with three replications per treatment. The different rates of aluminium were applied in the form of $Al_2 (SO_4)_3$. The experiment consisted two sets with similar procedures. The first set consisted of common bean plants grown on lime-treated soil whereas the second set comprised common bean plants grown on lime-untreated soil.

2.4. Experimental procedure

Seeds of the two common bean genotypes were sown in pots (18 x18 cm) filled with 10 kg soil. At the time of planting, the soil was fertilized with phosphorus at the rate of 92 kg P_2O_5 per hectare. Six seeds were initially sown per pot and later thinned to four plants when the first trifoliate leaves unfolded. Aluminium and lime were applied four weeks prior to sowing the seeds and worked into the soil. Lime was applied at the rate of 20 g pot^{-1}(9 tonnes/hectare) after determining by the incubation method. Pots were watered periodically with tap water to the approximate field capacity to facilitate normal plant growth. All other recommended agronomic management practices including watering, weeding, etc were done as required.

2.5. Collection and Preparation of Samples

Three plants per treatment were sampled 25 and 35 days after emergence (DAE). The plants were carefully dug out with their entire root system intact. The soil was separated from the roots by carefully shaking and loosening the ball of earth attached. The roots were gently washed under a jet of tap water until they came out clean. The samples were divided into roots, stems, and leaves. The plant parts were oven-dried at 65°C to a constant weight in a forced draft oven for 48 hours to determine dry biomass yield. The dry matter partitioned to the leaves, stems, and roots of each genotype was calculated by dividing the dry weight of each plant component by the total dry weight and expressed as a percentage [(*i.e*. leaf fraction (Lf), stem fraction (Sf) and root fraction (Rf)]. Root to shoot ratio was also calculated by dividing the root biomass by the biomass of the aerial part of the plant.

2.6. Growth Analysis

To investigate the effect of soil acidity on growth rate of the two common bean genotypes, absolute growth rate (AGR, g day^{-1}), relative growth rate (RGR, g g^{-1} d^{-1}), net assimilation rate (NAR, g m^{-2} d^{-1}), leaf area ratio (LAR, cm^2 g^{-1}), specific leaf area (SLA,cm^2 g^{-1}) and leaf weight ratio (LWR, g g^{-1}) were calculated according to [11]. Growth data were recorded using destructive sampling at both harvests.

2.8. Data Analysis

The data were subjected to analysis of variance (ANOVA) to determine significant differences among treatments for various parameters. Means of the treatments that exhibited significant differences were separated using the least significant difference (LSD) test at 5% level of significance [12].

3. RESULTS

3.1. Effects of aluminium on Growth Characteristics

Growth characteristics were significantly (*P*=.05) influenced by the main as well as the interaction effects of aluminium rates as well as the common bean genotypes (Table 1). Similarly, aluminium rate interacted with genotype to influence a number of growth characteristics of the plants. On average, the genotypes produced significantly higher leaf area in lime-treated soil than in lime-untreated soil (Figure 2). Twenty-five and thirty-five days after emergence, leaf area under lime-untreated soil decreased by 7.6 and 5.3%, respectively, relative to the lime-treated soil. Leaf area was markedly reduced as the aluminium applied increased in both lime-treated and lime-untreated soils. However, the magnitude of reduction was higher in lime-untreated soil (Figure 2). New BILFA 58 had higher leaf area than Roba 1 at each aluminium level both under lime-treated and lime-untreated soils (Figure 2). This effect may have resulted from the reduction in leaf area by 2.94 and 0.69% for new BILFA 58 and by 15.01 and 13.2% for Roba 1 for the first and second harvests, respectively, under the lime-untreated soil.

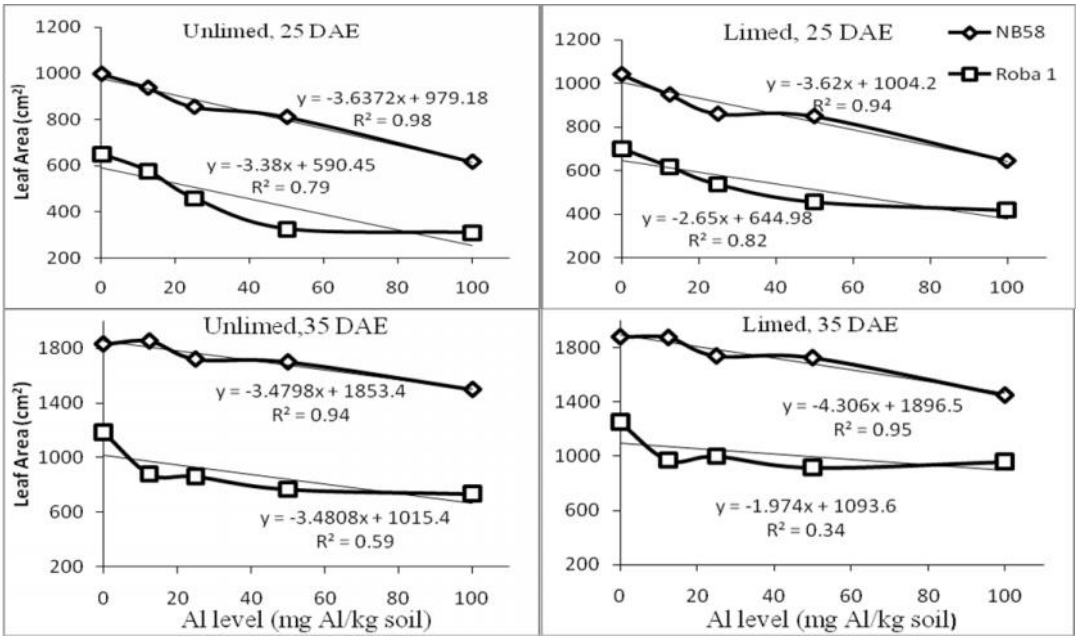

Figure 2. Leaf area (cm^2) of the two common bean genotypes grown under different levels of aluminium on lime treated (L) and lime untreated (UL) soil at 25 and 35 days after emergence (DAE)

Table 1. Mean squares of leaf area, growth analysis, dry matter partitioned, and shoot to root ratio, and means of unlimed and limed, of common bean genotypes as affected by alumnuimum treatement and genotyeps on lime treated and untreated soils.

Parameters	Lime	Mean	Al	G	Al*G	Error
Leaf Area (25)	UL	653.2^{b}	124305.5***	1077694.1***	6729.9*	1599.2
	L	707.1^{a}	99461***	781595***	5542^{NS}	3169.0
Leaf area (35)	UL	1303.9^{b}	129772.7***	5267391.5***	26256.9***	1647.3
	L	1377.4^{a}	106277***	3834098***	38628***	5136
Average growth	UL	0.65^{b}	0.177***	2.56***	0.0041*	0.00113
rate (AGR, g/d)	L	1.04^{a}	0.27***	3.772***	0.017*	0.0048
Relative Growth	UL	0.09^{b}	0.00095***	0.00056**	0.00006^{ns}	0.00005
Rate(RGR,)	L	0.14^{a}	0.00021**	.0053***	0.0004***	0.00004
Net Assimilation	UL	6.45^{b}	4.6***	38.943***	0.579*	0.129
Rate (NAR,	L	10.03^{a}	5.14***	34.514***	1.322*	0.435
Leaf weight	UL	0.59^{b}	0.00034^{ns}	0.0036**	0.0015*	0.0004
Ratio(LWR)	L	0.62^{a}	0.003	0.0021^{ns}	0.0057***	0.0008
Specific Leaf Area	UL	272.5^{b}	2898.6***	113365.4***	1346.2**	203.6
(SLA)	L	285.9^{a}	1831.7^{ns}	16807.9***	1888.3^{ns}	995.5
Leaf Area Ratio	UL	149.1^{a}	165.8^{ns}	12972.6***	661.3***	60.3
	L	137.1^{b}	366.3**	76.3^{ns}	253.9*	62.0
Leaf fraction (25)	UL	51.2^{b}	8.57^{ns}	151.92***	26.9*	6.86
	L	56.2^{a}	72.73***	0.73^{NS}	36.5**	6.43
Leaf Fraction (35)	UL	48.9^{a}	36.62***	41.75**	22.17**	3.403
	L	45.7^{b}	17.82^{NS}	8.99^{NS}	20.01^{NS}	8.04
Stem fraction (25)	UL	32.0^{a}	41.35***	0.432^{NS}	21.97*	5.054
	L	19.2^{b}	26.53^{NS}	0.45^{NS}	109.04***	11.43
Stem fraction (35)	UL	35.1^{b}	8.69^{NS}	214.1***	31.54***	3.758
	L	36.9^{a}	12.2^{NS}	205.71***	32.01*	7.33
Root fraction (25)	UL	16.8^{b}	22.3***	168.41***	3.45*	1.1106
	L	24.6^{a}	25.8**	0.033^{NS}	30.72**	4.65
Root Fraction (35)	UL	16.01^{b}	22.4***	66.75***	1.62^{ns}	2.096
	L	17.4^{a}	8.2**	300.8***	9.9***	1.13
Shoot : Root (25)	UL	0.20^{b}	0.0048***	0.035***	0.00071*	0.0003
	L	0.33^{a}	68.21*	0.84^{NS}	89.6**	15.06
Shoot : Root (35)	UL	0.19^{b}	0.0046***	0.0134***	0.00031^{ns}	0.00043
	L	0.22^{a}	17.36**	647.35***	20.42***	2.474

Where; UL- unlimed, L- limed, 25 and 35 days after emergence, respectively
NS- non-significant, *-P(0.01-0.05), **= P(0.001-0.01), *** (P<0.001)

The differences in absolute growth rate (AGR) and relative growth rate (RGR) among aluminium rates, between the genotypes, and their interaction terms were significant (*P* = .01) for both lime-treated and lime-untreated soils (Table 1). AGR and RGR were higher for lime-treated than for lime-untreated soil. Roba 1 had relatively higher AGR and RGR in lime-treated soil than in lime-untreated soil (Figure 3a). The data revealed that aluminium toxicity had a detrimental effect on growth of both genotypes because AGR and RGR decreased considerably in response to the application of the increased rates of aluminium. On the other hand, application of lime reduced the effect of aluminium toxicity in this study. However, inhibitory effects of aluminium were observed as the level of Al applied was increased for both common bean genotypes. Plants supplied with 100 mg Al per kg soil had lower AGR and RGR than the other levels and the control treatment (Figure 3a). The reductions of AGR and RGR were greater when the genotypes were grown under lime-untreated soil than when they were grown under lime-treated soil. AGR and RGR decreased by 37.5 and 32.9%, respectively, for lime-untreated soil as compared to the lime-treated soil.

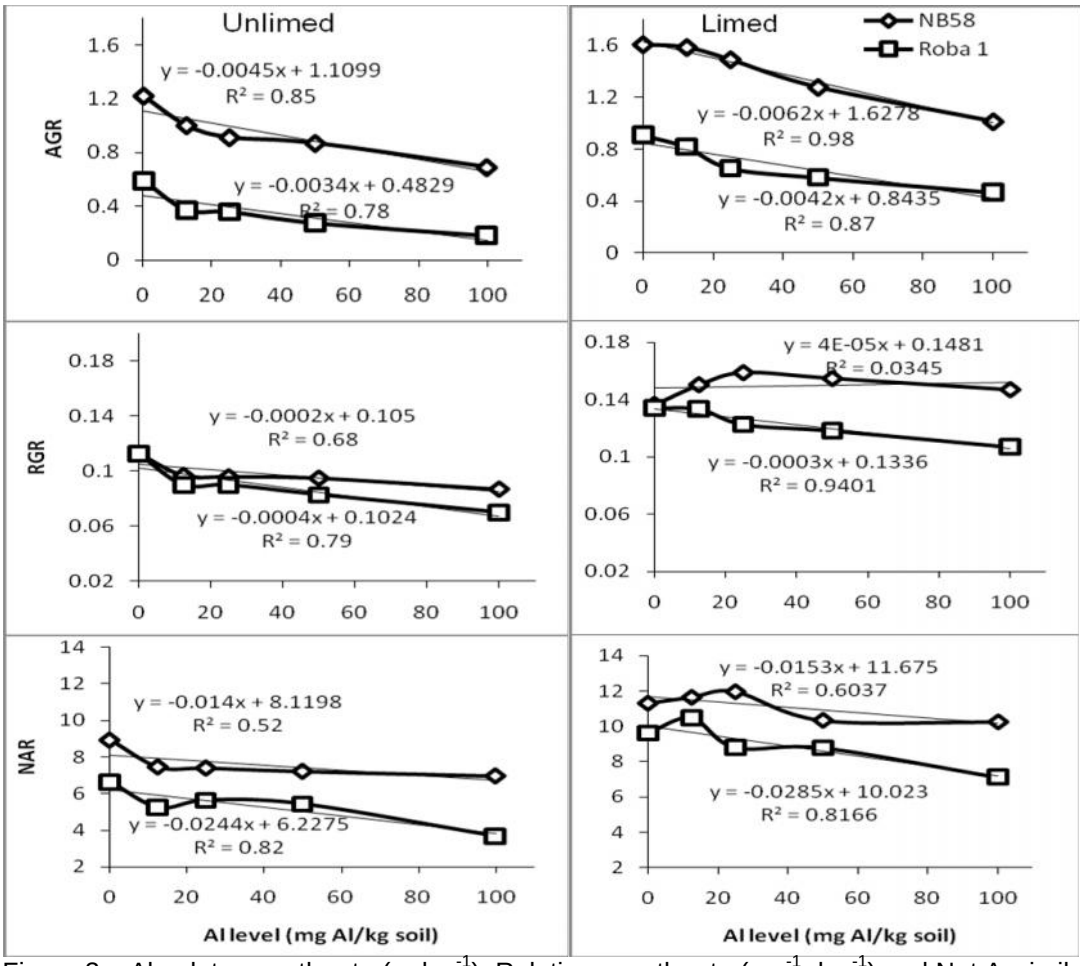

Figure 3a. Absolute growth rate (g day^{-1}), Relative growth rate (g g^{-1} day^{-1}) and Net Assimilation rate (g m^{-2}day^{-1}) of the two common bean genotypes grown under different rates of aluminium applied on lime treated-and lime untreated soils

Both the main and interaction effects due to aluminium rates and genotypes were significant for Net Assimilation Rate (NAR) under lime-treated and lime-untreated soil conditions. The NAR declined as the aluminium rates increased (Figure 3a). The highest NAR was recorded for the control (no aluminium) treatment whereas the lowest was at the highest Al rate under both soil liming regimes (Figure 3a). The rate of reduction in NAR increased with rates of aluminum applied and the reduction was higher for lime-untreated soil than for the treated soil. On average, the genotypes suffered 35.7% reduction in NAR when grown on lime-untreated soil as compared to when they were grown in lime-treated soil with similar rates of aluminum applied. Comparing the two genotypes, new BILFA 58 suffered a lower reduction in NAR (31.5%) than Roba 1, which suffered a 40.4% when grown under different rates of aluminium on the lime-untreated soil.

Differences among the aluminium levels, between the bean genotypes, and their interaction terms were significant (*P*=.05 for specific leaf area (SLA) under the lime-untreated soil (Table 1). New BILFA 58 had lower specific leaf area than Roba 1 under both soil treatment conditions (Figure 4). For new BILFA 58, specific leaf area (SLA) tended to increase as the aluminium level increased from 0 to 50 mg Al/kg soil and then declined at 100 mg Al/kg soil on lime-untreated soil. Similarly, SLA of Roba 1 increased with the increasing rate of Al except at the rate of 50 mg Al per kg soil (Figure 3b).

Both the main and the interaction effects due to aluminium rates and genotypes were significant (*p*=.05) for leaf area ratio (LAR) and leaf weight ratio (LWR) under lime-untreated soil condition. The main effect of aluminium rate and the interaction between aluminium rate and genotype were significant on leaf area ratio (LAR) and leaf weight ratio (LWR) for the lime-treated soil**.** Higher LWR was recorded for the untreated soil whereas LAR was higher for the lime-treated soil (Figure 3b). Higher leaf weight ratio was recorded for new BILFA 58 than Roba 1 at the different rates of aluminium applied.

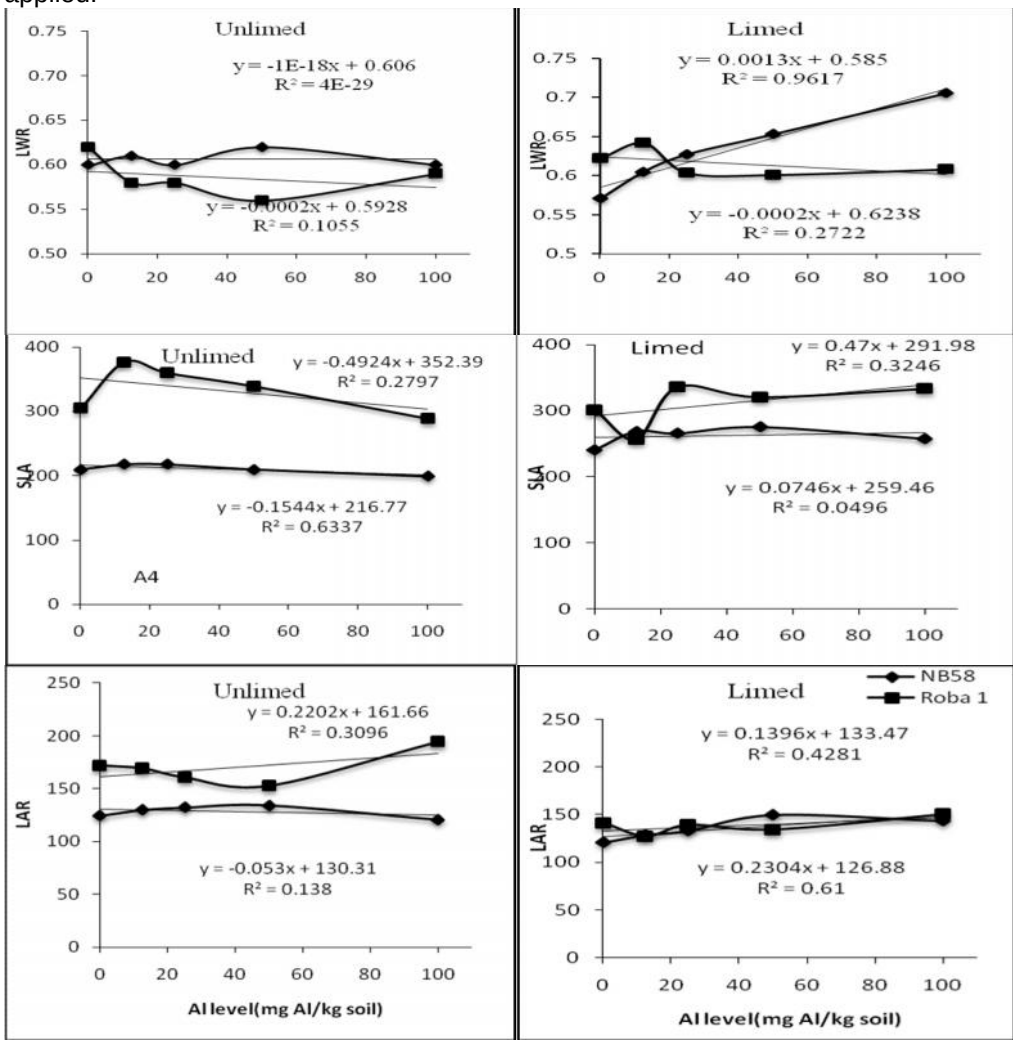

Figure 3b.Leaf Area Ratio(g g^{-1}), Specific Leaf Area (cm^2 g^{-1}) and Leaf Area Ratio (cm^2 g^{-1}) of the two common bean genotypes grown under different rates of aluminium applied on lime treated and lime untreated soils

3.2. Dry Matter Partitioning

A highly significant difference (*P* = .001) among Al levels were found for leaf fraction at the first harvest in both lime-treated and lime-untreated soils (Table 1). However, the difference between the two genotypes was observed only under lime-untreated soil. The proportion of dry matter partitioned to leaf was higher for new BILFA 58 than for Roba 1 twenty-five DAE whereas it was the reverse 35 DAE for the lime-untreated soil (Figure 4). In contrast genotypic differences for leaf fraction of the dry matter were not significant at both harvest times for the lime-treated soil (Table 1). Higher leaf fraction to total biomass was found for plants grown under lime treated soil condition at 25 DAE compared with lime-

treated soil. However, leaf fraction was higher in lime untreated soil in the second harvest(35 DAE) as compared to lime treated soil(Table 1).The leaf fraction was higher for the first harvest (25 DAE) in both lime-untreated and lime-treated soils than the second harvest (35 DAE).

The main effects due to aluminium rates and genotypes and their interaction terms for the first harvest and main effect due to genotypes and the interaction term for the second harvest were significant for stem fraction under lime-untreated soil condition (Table 1). However, the main effects for aluminium (at both harvests) and genotype (at the first harvest) were not significant for the same parameter for the lime-treated soil. Proportionally, more dry matter was allocated to the stem 35 DAE than 25 DAE regardless of the liming treatment. Under both soil treatment regimes and harvesting times, Roba 1 had higher stem fraction than new BILFA 58 (Figure 4, 5). Twenty five DAE, the highest and lowest stem fractions were observed for the highest and lowest aluminium rates, respectively, under unlimed soil condition. However, stem fraction was the lowest at the highest aluminium rate for the lime-treated soil. Higher stem fraction of dry matter in Roba 1 was accompanied with lower allocation of biomass to leaf and root at higher rates of aluminium (Figure 5).

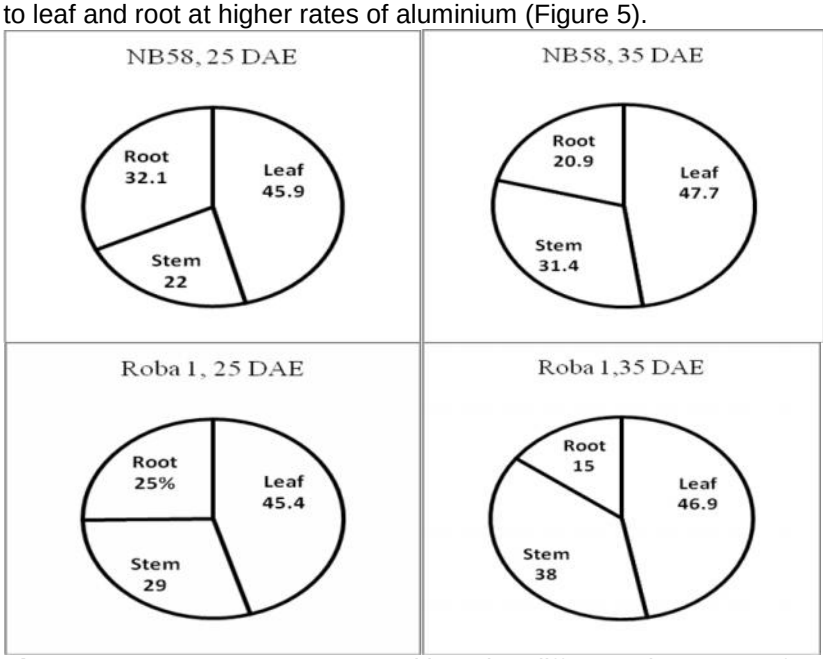

Figure 4. Perecent Dry matter partitioned to different plant parts of two common bean genotypes under different aluminium levels on lime untreated acid soils at 25 and 35 DAE

Genotypic differences in root fraction were observed in response to the different rates of aluminium applied (Table 1). Twenty-five as well as thirty-five DAE, the main effects due to aluminium rates and genotype and their interaction terms (except at 35 DAE for lime untreated soil) were significant for root fraction under the two soil liming regimes. New BILFA 58 had higher root proportion than Roba 1 at both harvesting times and under the two soil liming regimes (Figure 5). As the applied aluminium increased from 0 to 100 mg Al kg^{-1} soil, the fraction of dry matter allocated to the root was significantly reduced for the lime-untreated soil. With the application of increased rate of aluminium, the reduction was higher for Roba 1 than for new BILFA 58. In the case of lime-treated soil, Roba1 had relatively higher root fraction at the lower aluminium levels, which was reduced as the aluminium rates applied. However, Roba 1 had lower root fraction at all aluminium levels as compared to new BILFA 58 at 35 DAE (Figure 5). The acid soil tolerant genotype (new BILFA 58) exhibited an increase in root fraction in response to increasing rates of aluminium under the unlimed soil condition (Figure 5) and had higher root fraction in both soil types as compared to Roba 1.

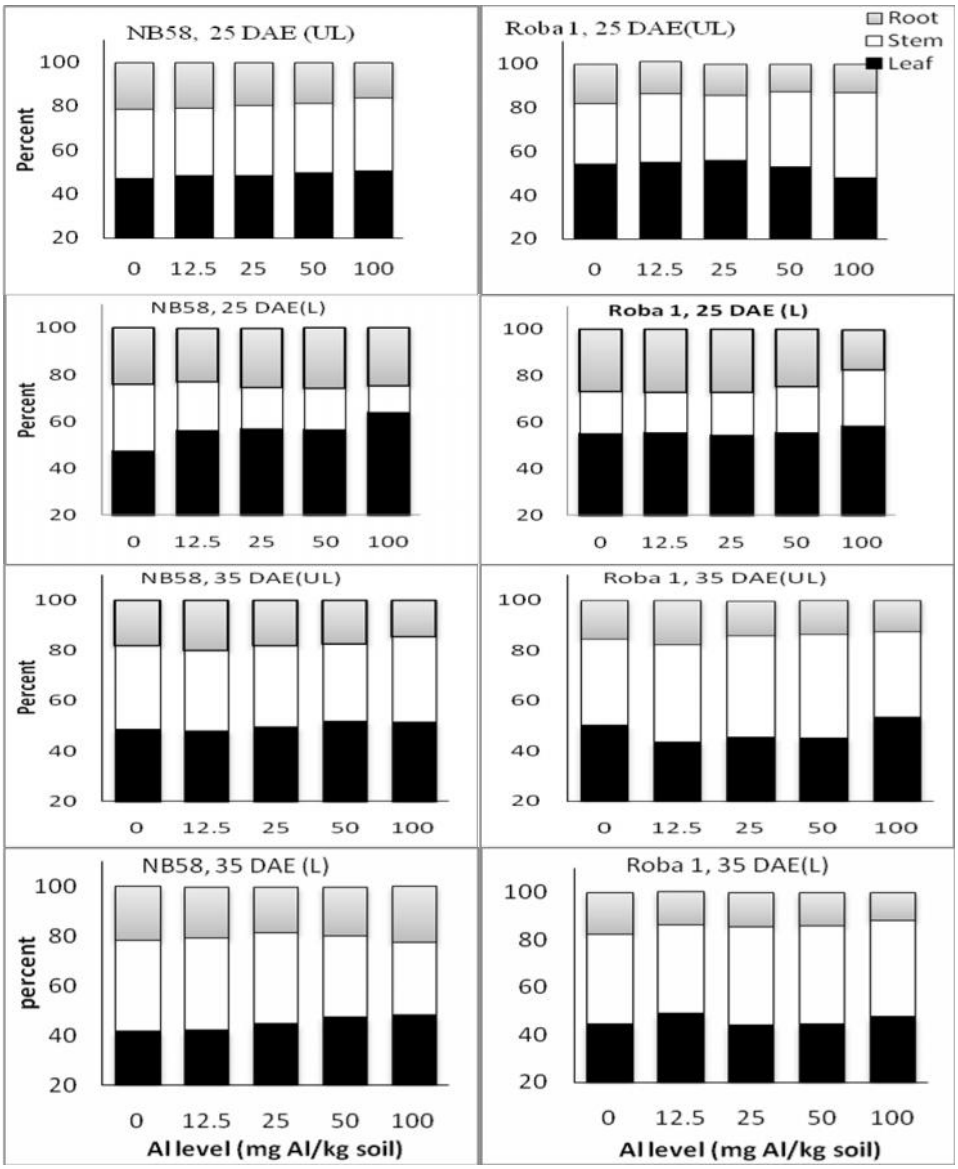

Figure 5. Dry matter partitioned to leaves, stems and roots of two common bean genotypes (new BILFA 58 and Roba 1) grown under different aluminium levels on lime-treated(L) and lime-untreated(UL) soils 25 and 35 days after emergence(DAE).

3.3. Root to Shoot Ratio

The main effects due to aluminium rates, genotypes, and their interaction terms (except for lime-treated soil) were significant (*P*=.05) for root to shoot weight ratio 25 DAE under the two soil liming regimes (Table 1). The trends were more or less similar 35 DAE under both soil liming regimes. Root to shoot weight ratio was higher 25 DAE compared to the measurements made 35 DAE. Moreover, plants grown on lime-treated soil had significantly higher root to shoot ratio than those grown on untreated soil (Figure 6). At both harvesting times and under the two soils liming regimes, root to shoot ratio decreased with increased rates of aluminium applied with new BILFA 58 having higher ratio than Roba 1.

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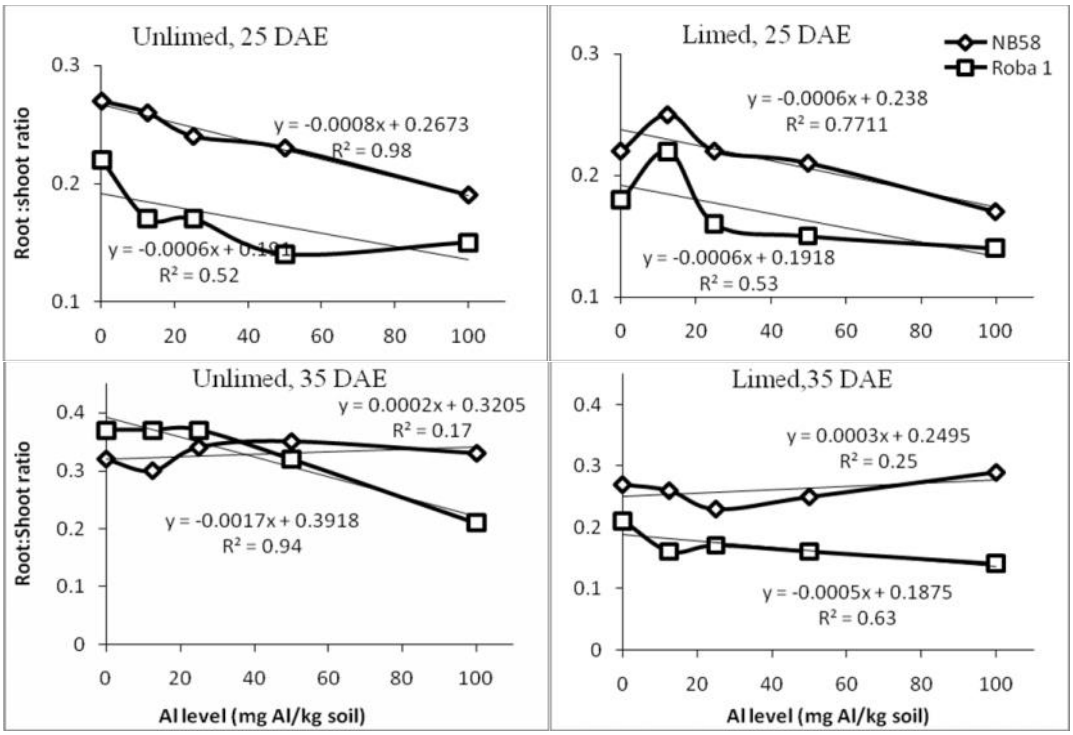

Figure 6. Root to shoot ratio of two common bean genotypes in response to different levels of aluminum under lime treated and lime untreated soils at 25 and 35 DAE

4. DISCUSSION

Soil acidity significantly reduced the overall growth of both genotypes irrespective of their genetic background. This was evident from the decline in the different growth parameters in response to the increased aluminium rates applied. Leaf areas of both genotypes were adversely affected in response to increased aluminium rates under both soil liming regimes. Leaf development of Roba 1was more affected than that of new BILFA 58 at all rates of Al application for the lime-untreated soil. The reduction in leaf area of the genotypes under lime-untreated soil could be related to P deficiency, which occurs under soil acidity Bolan *et al*, [13], which results in inhibited leaf expansion as reported by [14]. According to several reports, Al-induced leaf necrosis Roy *et al*, [15]; Zhang *et al.* [10], leaf yellowing Roy *et al*, [15], stunted leaf growth Wang *et al*, [2] and late leaf maturity (Rout *et al*, 2001) are effects of Al-toxicity. The increase in leaf area from 25 to 35 DAE was higher for new BILFA 58 than Roba 1. The rate of aluminium applied was inversely related to leaf area development for both genotypes (Figure 2) concurring with the reports of Thornton *et al*. [17] that aluminum reduced expansion rates of leaves by up to 50% compared with control seedlings in honey locust(*Gleditsia triacanthos* L).

Application of aluminium resulted in significant decline in absolute and relative growth rates of both genotypes grown under lime-treated and lime-untreated soils. However, the reduction was relatively less for new BILFA 58 than Roba 1. The results of this study revealed that aluminium tolerant genotype exhibited better growth performance under strongly acidic soil condition when lime was applied. Corroborating these results, [18] reported beneficial effects of increasing Ca concentration in the nutrient solution and liming on plant growth under Al stress.

The higher NAR values of new BILFA 58 as compared to Roba 1 suggested that this genotype was more efficient in producing dry matter under aluminum stress than Roba 1. On average, new BILFA 58 had higher NAR than Roba 1, demonstrating the inherently higher photosynthetic efficiency of the former genotype over a range of growing conditions. Higher NAR for plants grown on lime-treated soil than the untreated one could be due to decreased toxicity effect of aluminium in the latter condition.

Higher NAR of the genotypes under lime treated soil condition could be related to improved availability of nutrients needed for growth and development of the crop. The reduction in biomass yield under lime-untreated soil especially for Roba 1 resulted in higher leaf area ratio than under lime-treated soil. In contrast, New BILFA 58 produced relatively higher biomass yield and leaf area under the two soil liming regimes. On the contrary, aluminium application did not have significant effect on leaf weight ratio on lime untreated soil. This was probably due the reduction of both total biomass yield and leaf biomass yield of the two genotypes as the rate of the aluminium applied was increased. The higher SLA in both lime-treated and lime-untreated soils for Roba 1 was found perhaps owing to the higher reduction in leaf biomass than leaf area for both soil liming regimes. On the other hand, new BILFA 58 had relatively higher leaf biomass yield and leaf area under both soil liming regimes, which has resulted in lower SLA.

Several studies have reported genotypic variability in plant growth, physiology, and quality in response to Al [19; 20]. In addition to the leaf area differences, the absolute growth rate, relative growth rate, net assimilation rate of the new BILFA 58 common bean genotype was somewhat less affected than Roba 1 under different levels of aluminum applied in lime-treated and lime-untreated soils. Therefore, these growth indices appear to be useful in germplasm screening for Al tolerance. The use of lime can relieve the toxicity of acid soil, but these are not permanent solutions.

In nutrient deficient plants, maintenance of the export of photo-assimilates from the source leaves allow continued root growth and thus an increase in root fraction [21]. Therefore, it is likely that new BILFA 58 maintained the synthesis and export of assimilates to ensure continued root growth, which may have led to the increased root fraction even when higher rates of aluminium were applied. Furthermore, possession of larger root fraction by new BILFA 58 could explain why the genotype performed better than Roba 1 under low pH soil. Plants grown on lime-treated soil had significantly higher root to shoot ratio than those grown on untreated soil (Figure 6). Higher root to shoot weight ratio that was maintained at higher aluminium toxicity levels for new BILFA 58 apparently enhanced growth and yield of the genotype than Roba 1 grown under a similar condition. These results confirm that common bean genotypes vary in the ability to partition biomass to roots or shoots depending on the degree of aluminium toxicity and the trait can as such be used to differentiate genotypes that are tolerant or sensitive to aluminium toxicity. Genetic differences in root biomass, root-to-shoot weight ratios, and root biomass distribution have already been reported for common beans [22]. Thus, there is considerable potential for improving or selecting common bean genotypes for tolerance to aluminium toxicity through genetic manipulation based on the pattern of root to shoot assimilate partitioning.

5. CONCLUSION

With the increase in rate of aluminium applied, almost all growth characteristics considered declined under both contrasting soil liming regimes. However, the reduction was lower on lime-treated soil and for the genotype new BILFA 58. Dry matter partitioning to different parts of the bean plant was also affected depending on the rate of aluminium applied and the crop growth stage considered. Relatively higher biomass was partitioned to roots by new BILFA 58 than by Roba 1 on both lime-treated and lime-untreated soil conditions. Dry matter partitioning to roots in response to increased rate of Al was higher 25 DAE than the later harvesting time, i.e., 35 DAE. Lime application generally improved growth and dry matter partitioning of the genotypes, possibly through decreasing the toxicity effect of aluminium and improving the availability of nutrients for uptake by the growing plant. Therefore, growing common bean genotypes that are tolerant to acid soil with supplemental application of lime could enhance growth performance and productivity of the crop in humid tropics, where soil acidity is a menace to the production of the crop.

6. ACKNOWLEDGMENTS

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AUTHORS' CONTRIBUTIONS

The first author (Hirpa) designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. The rest author edit, comment on the protocol, evaluate the experiment setup, evaluate and monitor all the activities undertaken by the student (Hirpa), edit and comment on the first draft of the manuscript. The First two Advisors contribute more than the last two advisors. All authors read and approved the final manuscript.

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