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

Hirpa Legesse[1*], Nigussie-Dechassa R.[2], Setegn Gebeyehu[2*], Geremew Bultosa[3], Firew Mekbib[4]

[1]*Wollega University, department of plant science, P. O. Box 395, Nekemte, Ethiopia*

[2] *Haramaya University, Department of Plant sciences, P. O .Box 138, Dire Dawa, Ethiopia*

[2*] *Oxfam* OA HARO, P.O. Box- 25779, Addis Ababa, Ethiopia

[3]Department of Food Science and Technology, Botswana College of Agriculture, GABORONE

[4]*Haramaya University, Department of Plant sciences, P. O .Box 138, Dire Dawa, Ethiopia*

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

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*

105 *al.* [7], and Barceló and Poschenrieder [8]. Most of the mechanisms studied are related to limited root
106 growth and development or their consequences. Comparatively, less information exists about the
107 effects of Al^{3+} on leaves than on roots (9). Hence, it is suggested that more attention should be paid to
108 aerial tissues in future studies, which are important in revealing Al toxicity and mechanisms of plant
109 tolerance to Al stress [10].
110
111 A preliminary field screening of common bean genotypes in western Ethiopia has demonstrated the
112 presence of genetic variability among genotypes. Studying responses of selected genotypes with
113 contrasting tolerance to aluminium toxicity may help in generating information that could be utilized by
114 breeding programmes aimed at developing aluminium-tolerant cultivars for areas where aluminium-
115 induced soil acidity remains the key environmental constraint. The objective of this study was to test
116 the hypothesis that differences exist in growth, dry matter partitioning, and root to shoot ratio among
117 common bean genotypes selected for soil acidity tolerance when subjected to different rates of
118 aluminum applied on lime-treated and lime-untreated soil.
119

120 **2. MATERIALS AND METHODS**

121 **2.1. Description of the Study Area**

122 The experiment was conducted at Nekemte soil laboratory in western Ethiopia. The experimental site
123 is located at $9^0 08'$ N latitude and $36^0 46'$ E longitude at the altitude of 2080 metres above sea level.
124 According to the weather data recorded at the Nekemte Meteorological Station, the average annual
125 rainfall of the study site is 1300 mm with 725 mm for the experimental period   (July – October) and the
126 monthly mean minimum and maximum temperatures were between 10-15°C and 24 to 28 ^{0}C (Figure
127 1). The soil used for the pot experiment has a pH (H_2O) value of 4.81, exchangeable acidity of 4.92
128 cmol/kg soil, exchangeable Al of 3.1 cmol/kg soils, and acid saturation of 53.3 % before applying the
129 treatments.
130
131 **2.2. Description of Planting Materials**

132 Screening experiments were conducted in 2009 and 2010 in the field at the soil pH of 4.45 and in pots
133 at the pH of 4.8, respectively. Common bean genotypes named new BILFA 58 (NB 58) and Roba1
134 were identified as the most tolerant and sensitive genotypes to soil acidity, respectively. New BILFA 58
135 is a genotype with type III growth habit and large-sized seed (53 g per 100 seed) whereas Roba 1 is a
136 small-seeded (22 g per 100 seed) commercial cultivar in Ethiopia with type II growth habit [11]
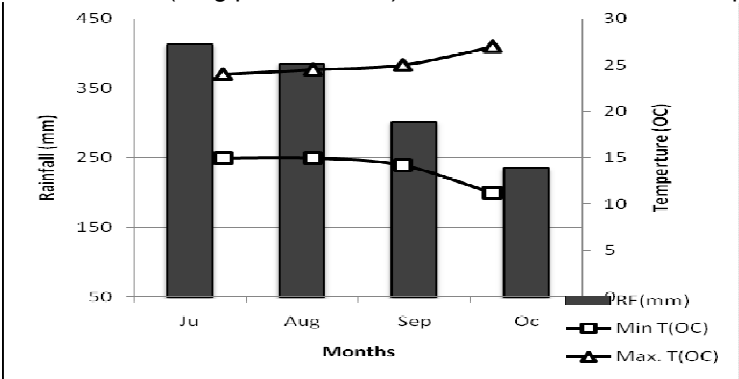

137

138 Figure 1. Rainfall distribution and mean minimum and maximum temperature of the experimental site,
139 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 [pH (H_2O)- 6.1] 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 [12]. 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 [13].

3. RESULTS

3.1. Effects of aluminium on Growth Characteristics

182 Growth characteristics were significantly (*P*=.05) influenced by the main as well as the interaction
183 effects of aluminium levels as well as the common bean genotypes (Table 1). Similarly, aluminium
184 level interacted with genotype to influence a number of growth characteristics of the plants. On
185 average, the genotypes produced significantly higher leaf area in lime-treated soil than in lime-
186 untreated soil (Figure 2). Twenty-five and thirty-five days after emergence, leaf area under lime-
187 untreated soil decreased by 7.6 and 5.3%, respectively, relative to the lime-treated soil. Leaf area was
188 markedly reduced as the aluminium applied increased in both lime-treated and lime-untreated soils.
189 However, the magnitude of reduction was higher in lime-untreated soil (Figure 2). New BILFA 58 had
190 higher leaf area than Roba 1 at each aluminium level both under lime-treated and lime-untreated soils
191 (Figure 2). This effect may have resulted from the reduction in leaf area by 2.94 and 0.69% for new
192 BILFA 58 and by 15.01 and 13.2% for Roba 1 for the first and second harvests, respectively, under
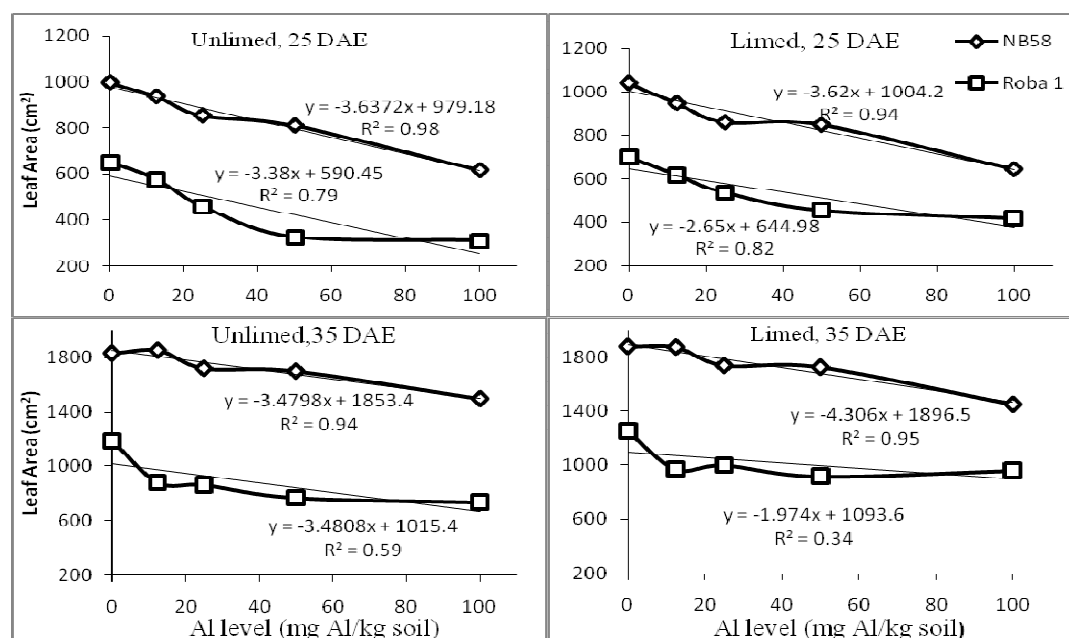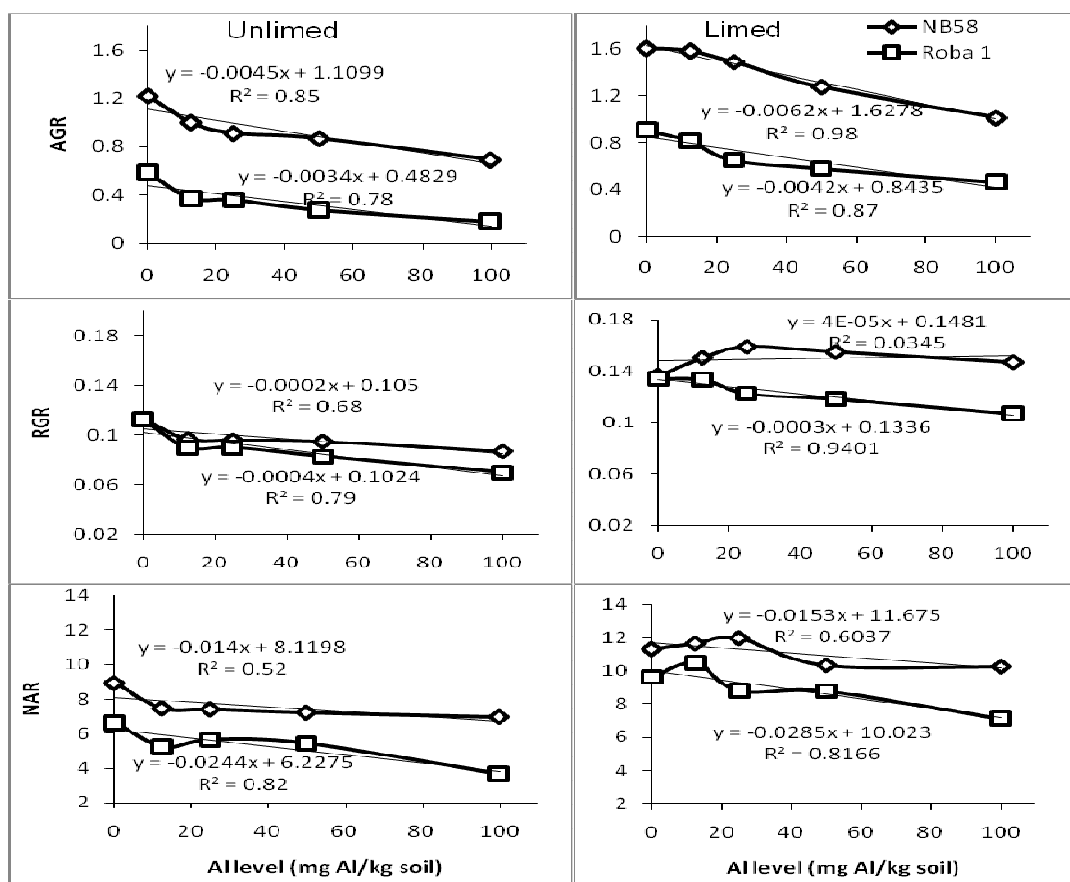193 the lime-untreated soil.
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198 Figure 2. Leaf area (cm^2) of the two common bean genotypes grown under different levels of
199 aluminium on lime treated (L) and lime untreated (UL) soil at 25 and 35 days after emergence (DAE)

200
201 The differences in absolute growth rate (AGR) and relative growth rate (RGR) among aluminium
202 levels, between the genotypes, and their interaction terms were significant (*P* = .01) for both lime-
203 treated and lime-untreated soils (Table 1). AGR and RGR were higher for lime-treated than for lime-
204 untreated soil. Roba 1 had relatively higher AGR and RGR in lime-treated soil than in lime-untreated
205 soil (Figure 3a). The data revealed that aluminium toxicity had a detrimental effect on growth of both
206 genotypes because AGR and RGR decreased considerably in response to the application of the
207 increased rates of aluminium. On the other hand, application of lime reduced the effect of aluminium
208 toxicity in this study. However, inhibitory effects of aluminium were observed as the level of Al applied
209 was increased for both common bean genotypes. Plants supplied with 100 mg Al per kg soil had lower
210 AGR and RGR than the other levels and the control treatment (Figure 3). The reductions of AGR and
211 RGR were greater when the genotypes were grown under lime-untreated soil than when they were
212 grown under lime-treated soil. AGR and RGR decreased by 37.5 and 32.9%, respectively, for lime-
213 untreated soil as compared to the lime-treated soil.

214
215

216 Table 1. Mean squares of leaf area, growth analysis, dry matter partitioned, and shoot to root ratio,
217 and means of unlimed and limed, of common bean genotypes as affected by alumnuimum ==levels== and
218 genotyeps on lime treated and untreated soils.
219

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==	$==2.45^a==$	$==0.52^{***}==$	$==28.1^{***}==$	$==0.052^{ns}==$	==0.059==
	==L==	$==2.52^a==$	$==0.68^{***}==$	$==6.27^{***}==$	$==0.026^{ns}==$	==0.014==
==Leaf Fraction (35)==	==UL==	$==6.22^b==$	$==8.73^{***}==$	$==254.9^{***}==$	$==0.31^*==$	==0.096==
	==L==	$==7.66^a==$	$==9.19^{***}==$	$==183.13^{***}==$	$==0.34^{NS}==$	==0.25==
==Stem fraction (25)==	==UL==	$==1.55^a==$	$==0.079^{**}==$	$==13.94^{***}==$	$==0.018^{ns}==$	==0.017==
	==L==	$==0.89^b==$	$==0.58^{***}==$	$==1.15^{***}==$	$==0.47^{***}==$	==0.0203==
==Stem fraction (35)==	==UL==	$==4.27^b==$	$==4.87^{***}==$	$==82.04^{***}==$	$==0.28^{ns}==$	==0.15==
	==L==	$==6.15^a==$	$==13.02^{***}==$	$==89.58^{***}==$	$==2.25^{**}==$	==0.37==
==Root fraction (25)==	==UL==	$==0.89^b==$	$==0.36^{***}==$	$==3.35^{***}==$	$==0.011^{ns}==$	==0.008==
	==L==	$==1.12^a==$	$==0.428^{**}==$	$==1.14^{***}==$	$==0.027^*==$	==0.008==
==Root Fraction (35)==	==UL==	$==2.35^b==$	$==1.55^{***}==$	$==34.09^{***}==$	$==0.14^{ns}==$	==0.11==
	==L==	$==3.15^a==$	$==3.35^{***}==$	$==68.13^{***}==$	$==0.22^{**}==$	==0.041==
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

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

Figure 3. 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 levels of aluminium applied on lime treated-and untreated soils

Both the main and interaction effects due to aluminium levels 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 3). The highest NAR was recorded for the control (no aluminium) treatment whereas the lowest was at the highest Al level under both soil liming regimes (Figure 3). 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 level of 50 mg Al per kg soil (Figure 4).

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 level 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 4). Higher leaf weight ratio was recorded for new BILFA 58 than Roba 1 at the different levels of aluminium applied.
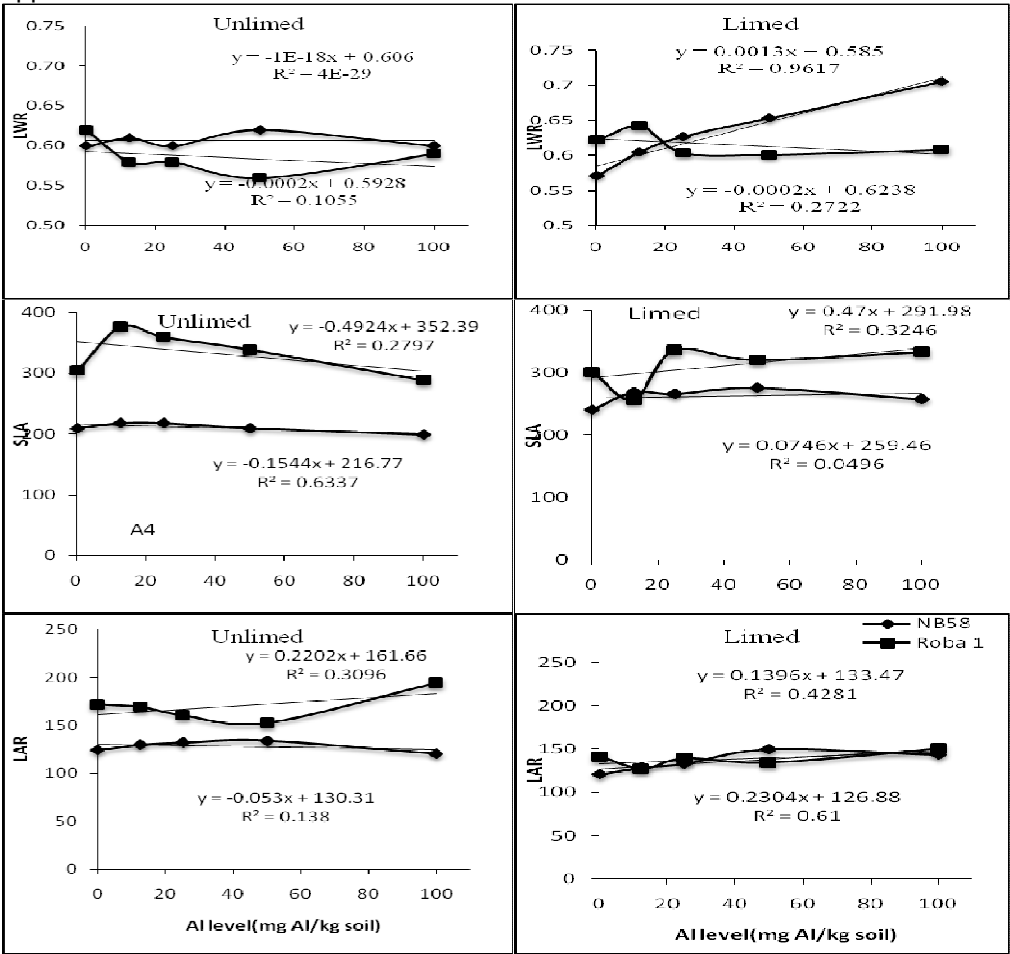
Figure 4.Leaf Area Ratio (g g^{-1}), Specific Leaf Area (cm^2 g^{-1}) and Leaf Area Ratio (cm^2 g^{-1}) of the two common bean genotypes grown under different levels of aluminium   applied on lime treated and untreated soils

3.2. Dry Matter Partitioning

A highly significant difference (P = .001) among Al levels and genotypes were found for dry matter partitioned to the leaf, stem and root at the first and second harvests in both lime-treated and untreated soils (Table 1). However, the Al level by genotype interaction was significant (P=.05) only for leaf (25 DAE) lime untreated soil, stem and root for the first and second harvest in lime treated soil (Table 1). The proportion of dry matter partitioned to leaf, stem and root was higher for new BILFA 58 than for Roba 1 for both harvests and liming regimes (Figure 5). Higher dry matter partitioned to leaf to total biomass was found for plants grown under lime treated soil condition at 25 DAE compared with untreated soil. Proportionally, more dry matter was allocated to the stem 35 DAE than 25 DAE regardless of the liming treatment. 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 dry matter produced by each plant part was significantly reduced for both genotypes and liming regimes. However, the reduction was higher for Roba 1 and lime untreated soil (Figure 5).
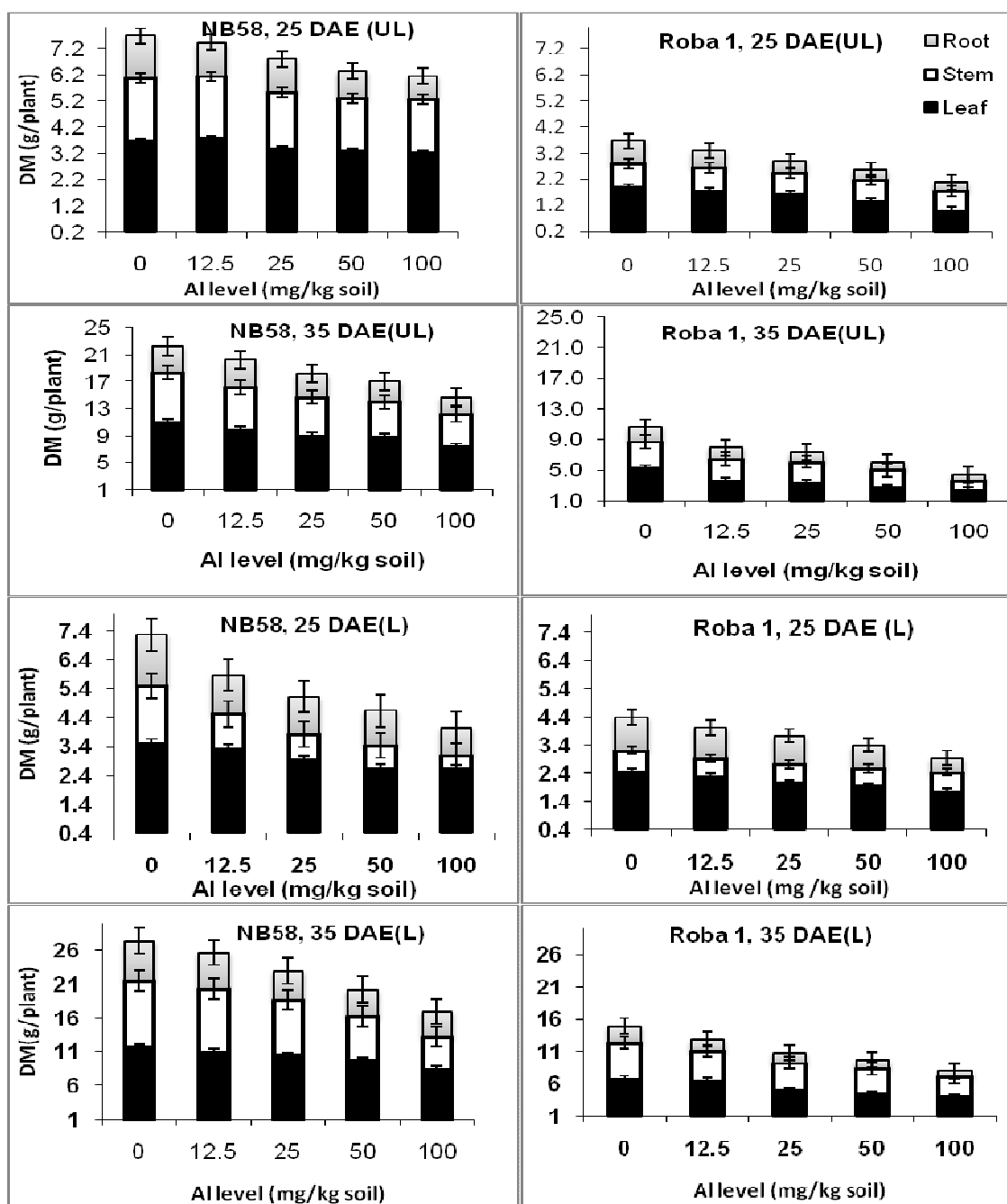
Figure 5. Dry matter (DM) partitioned (g/plant) to leaves, stems and roots of two common bean genotypes (new BILFA 58 and Roba 1) grown under different aluminium levels on lime-treated(L) and untreated(UL) soils 25 and 35 days after emergence(DAE).

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

296 to shoot weight ratio was higher 25 DAE compared to the measurements made 35 DAE. Moreover,
297 plants grown on lime-treated soil had significantly higher root to shoot ratio than those grown on
298 untreated soil (Figure 6). At both harvesting times and under the two soils liming regimes, root to shoot
299 ratio decreased with increased rates of aluminium applied with new BILFA 58 having higher ratio than
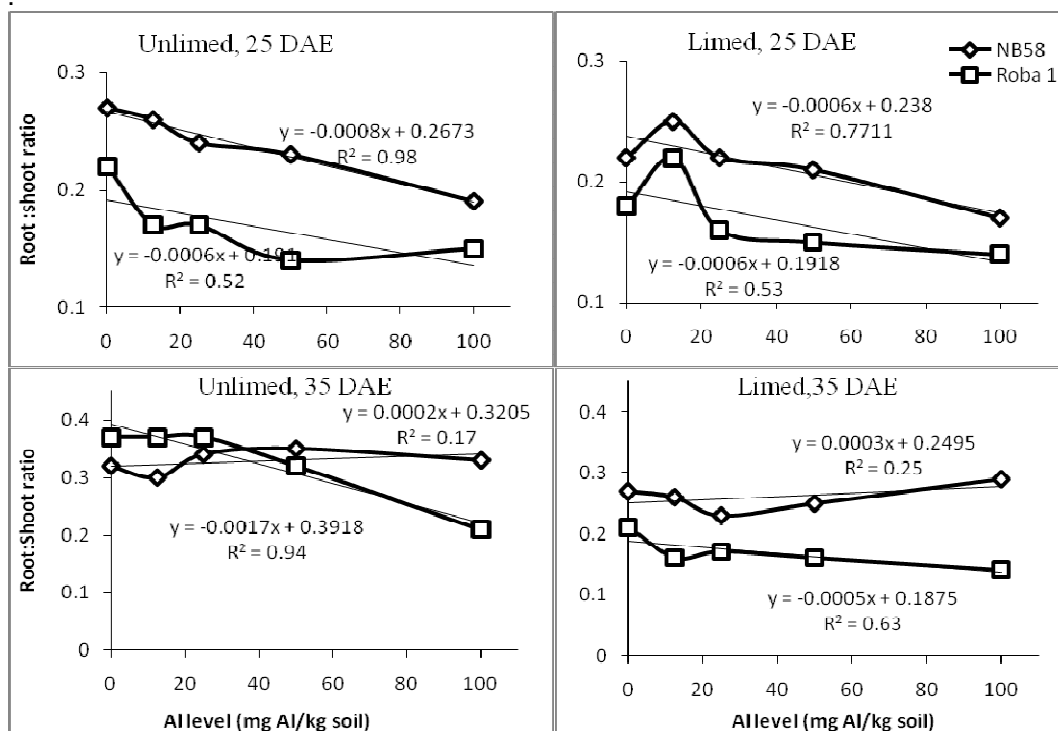300 Roba 1.
301 .

302

303
304 Figure 6. Root to shoot ratio of two common bean genotypes in response to different levels of
305 aluminum under lime treated and lime untreated soils at 25 and 35 DAE
306
307 **4. DISCUSSION**
308
309 Soil acidity significantly reduced the overall growth of both genotypes irrespective of their genetic
310 background. This was evident from the decline in the different growth parameters in response to the
311 increased aluminium levels applied. Leaf areas of both genotypes were adversely affected in response
312 to increased aluminium levels under both soil liming regimes. Leaf development of Roba 1 was more
313 affected than that of new BILFA 58 at all levels of Al application for the lime-untreated soil. According
314 to several reports, Al-induced leaf necrosis Roy *et al,* [14]; Zhang *et al.* [10], leaf yellowing [15],
315 stunted leaf growth Wang *et al,* [2] and late leaf maturity, Rout *et al.*[16] are effects of Al-toxicity. The
316 increase in leaf area from 25 to 35 DAE was higher for new BILFA 58 than Roba 1. The rate of
317 aluminium applied was inversely related to leaf area development for both genotypes (Figure 2)
318 concurring with the reports of Thornton *et al.* [17] that aluminum reduced expansion rates of leaves by
319 up to 50% compared with control seedlings in honey locust(*Gleditsia triacanthos* L).
320
321 Application of aluminium resulted in significant decline in absolute and relative growth rates of both
322 genotypes grown under lime-treated and lime-untreated soils. However, the reduction was relatively
323 less for new BILFA 58 than Roba 1. The results of this study revealed that aluminium tolerant
324 genotype exhibited better growth performance under strongly acidic soil condition when lime was
325 applied. Corroborating these results, [18] reported beneficial effects of increasing Ca concentration in
326 the nutrient solution and liming on plant growth under Al stress.
327
328 The higher NAR values of new BILFA 58 as compared to Roba 1 suggested that this genotype was
329 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 to 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 dry matter partitioned to roots [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 dry matter partitioned to roots even when higher levels 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 aluminum toxic 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 levels 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 levels 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 aluminium toxic soils with supplemental application of lime could enhance growth performance and productivity of the crop in humid tropics, where aluminium toxicity is a menace to the production of the crop.

6. ACKNOWLEDGMENTS

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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