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Effect of Nitrogen Fixation on Yield and some Yield Component of Common Bean (Phaseolus vulgaris L.) Genotypes under Moisture Stress

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Abstract
Moisture stress is a worldwide production constraint for common beans and biological nitrogen fixation. The effect of drought has been widely reported and is an important environmental factor resulting in crop yield losses. This study aims at assessing the effect of nitrogen fixation on yield and some yield component of common bean (*Phaseolus vulgaris* L.) genotypes under moisture stress levels. Experiments were carried out in screen house and field at Sokoine University of Agriculture. The genotypes used were Kijivu, Yellow, Msolini, Masusu, Kasukanywele, Uyole 04, Mbulamtwe, Bilfa-Uyole and G 51495 A, a non-nodulating genotypes as a check. The soil moisture was maintained at 100, 75, 50 or 25% of the soil's field capacity. Moisture stress reduced yield up to 67%. Genotypes Yellow (2.9 and 11.2g/palnt), Msolini (3.3 and 10.7g/plant), Masusu (3.6 and 7.7g/plant) and Bilfa Uyole (4.1 and 7.2g/plant) were observed to have some degree of drought tolerance based on its response under moisture stress environments for yield. These results suggest that moisture stress has a substantial impact on the general performance of common bean genotypes. Selection of superior performing genotypes under moisture stress, and integrating them into the breeding programs is an important to increase crop productivity.
Keywords; N_2-fixation; Drought; Nodulation; Legumes

1.0 Introduction

Common bean production is constrained by several environmental stresses. Moisture stress is a worldwide production constraint for common beans (Boutraa and Sanders, 2001). Bean is mostly grown in areas with terminal or erratic drought stress (Beebe *et al*., 2008). Molina *et al*. (2001) reported that water stress reduced grain yield of common bean cultivars by up to 60%. Moisture stress in common bean accelerated maturity of the crop, reduced grain yield and mean weight, of hundred seed weight (Molina *et al*., 2001). According to Frahm *et al*. (2004) and Shenkut and Brick (2003), moisture stress has substantial impact on common bean growth and seed yields. Razinger *et al*. (2010) also reported drought to be a major factor distressing growth and development of plants and causes reduction in crop yields.

The ability of common bean to fix atmospheric nitrogen gives them an advantage when grown on soils low in nitrogen (Kabahuma, 2013). The effect of drought on BNF has been widely reported and is considered to be the most important environmental factor resulting in crop yield losses (Marino *et al*., 2007). Low soil water potentials have known to inhibit nodulation and growth of rhizobia. Hence, to understand the factors that influence nitrogen fixation is vital (Schulze, 2004). Some workers revealed that both root and shoot tissues have major roles in control of nodulation and nitrogen fixation (Abd-Alla, 2011). Hence non-nodulating common bean line has been used for comparison against nodulating for superior BNF.

Greater accumulation of dry matter is one of the important inputs to assure total translocation of photosynthesis materials to the seed (Getachew, 2014). Rosales-Serna *et al*. (2004) reported differences in shoot biomass accumulation for dry bean cultivars grown under moderate to severe drought stress condition. Slower growth under stress allows a plant to divert assimilates and energy, otherwise used for shoots growth, into protective molecules to fight stress (Zhu, 2002). According to Lopes *et al*. (2011) improving plant productivity under drought condition requires selection for a higher biomass accumulating genotypes.

While many common bean genotypes have been developed, evaluating them tolerance to moisture stress is very crucial in efforts to select varieties with better productivity under stressed conditions. This study aimed at assessing the effects of moisture stress in the growth performance of some selected genotypes with regard to nodulation and nitrogen fixation. The most tolerant will be selected to be used as parents in breeding programs to enhance biological nitrogen fixation and productivity.

2.0 Material and methods

Experiments were carried out in screen house and field at Sokoine University of Agriculture (SUA), Latitude 6^o45^oS, Longitude 37^o40^oE, at the altitude of 547 meters above sea level. Maximum temperature was 28.6^0C, minimum temperature was 18.2 and 85% Relative Humidity. The soil was (66.7% sand, 30.3% clay and 2.92 silt), pH in water 5.92, CEC 15.2 meq/100g, N 0.22%, P 5.80 ppm and B 0.49 ppm. Eight genotypes were evaluated namely Kijivu, Yellow, Msolini, Masusu, Kasukanywele, Uyole 04, Mbulamtwe and BilfaUyole. Genotype G 51495 A, a non-nodulating genotype, was included, as a check. The experiment was laid out as split plot in the completely randomized design (CRD) with 4 replications. Pots of 4 litres capacity were filled with 4 kg of air-field soils. TSP fertilizer at the rate of 60 kg P/ha was incorporated into the soil prior to planting. Seeds were inoculated with rhizobia at 100 g /20 kg of seed; two plants per pot were maintained after germination. Two pots were established per treatment. Soil field capacity was calculated on soil dry basis. The pots were weighed in two days intervals to compensate the water loss and therefore the pot soil moisture was kept at 100%, 75%, 50% and 25% of field capacity according to treatment. Normal agronomic practices for bean production were followed. The following data were collected; Days to 50% flowering (measures the number of days when 50% of plants have one or more flowers), Days to 85% maturity (measures the number of days when 85% of plants had reached maturity), root lengths, plant height, shoot biomass and root biomass were oven dried at 60^0C before weighing and grain yields per plant .

2.1 Field experiments for evaluating selected genotypes

The experiment was in the split plot design laid out in the Randomized Completely Block Design (RCBD), with three replications. Watering regimes were the main plots while bean genotypes were the sub-plots. Each plot had 2 rows of 4 m long, and the plant spacing was 50 cm and 10 cm between and within rows respectively. The plots were irrigated, with soils kept at 100, 75, 50 or 25% of its field capacity. Normal agronomic practices for bean production were followed. Data were collected as above for pot experiments.

2.2 Determination of Reduction Indexes

A reduction index shows the effect of water stress on the assessed variables (Molina *et al*., 2001). The formula enables to estimate the extent of reduction in performance for a given variable. It was calculated as percentage reduction of performance without stress and with stress by the expression:

$$IR\% = \frac{\text{performance without stress} - \text{performance with stress}}{\text{performance without stress}} \times 100$$

Statistical analysis was carried out using the GenStat Fourteen Edition Statistical Package. Data were analysed by two way analysis of variance and treatment means were compared by Duncan Multiple Range Test (DMRT) at P = 0.05.

3.0 Result and Discussion

3.1 Analysis of variance (ANOVA) summary

Summary of analysis of variance for the studied variables is shown in table 1 and 2 for green-house and field experiment respectively. Significant variations were observed due to genotype, stress and the interaction of genotypes and stress.

Table 1: Analysis of variance for studied variables (mean squares) in the field

Source of variation	df	Plant height (cm)	Root length (cm)	Yield (kg/plant)	Shoot biomass (g)	Root biomass (g)	50%	85%
Rep	2	424.1	20.9	3057.9	52.4	3.3	3.1	64.6
Stress (S)	3	211.4	76.9**	10579.8***	351.3***	1.6*	10.5	22.3
Genotype (G)	8	599.1***	15.8	2484.4**	158.9**	0.4	128.8***	120.9***
S x G	24	251.6	12.4	697.6**	37.2	0.6	10.9**	6.7
Error	70	191.7	18.3	991.6	72.6	0.5	5.4	16.3

Table 2: Analysis of variance for studied variables (mean squares) in green-house

Source of variation	df	50% flowering	85% maturity	Plant height (cm)	Root length (cm)	Shoot Biomass (g)	Root Biomass (g)	Yield (g/plant)
Replication	3	37.8	22.8	59.0	42.5	45.4	0.1	21.8
Genotype(G)	8	176.5***	56.8***	34177.0***	87.9**	8.4ns	0.1	34.5***
Stress (S)	3	24.8*	10.9ns	5538.0*	126.9**	10.4ns	0.1**	43.5***
G x S	27	0.1ns	6.9ns	1873.0ns	30.3ns	5.7ns	0.01ns	5.9*
Error	108	0.1	8.3	1832.0	33.5	5.3	0.03	3.8

3.2 Effects of genotypes

The results from this study showed variations among genotypes for studied variables (Table 3 and 4). Since these genotypes were grown in the same medium, the variations may reflect their genetic potential in nutrient uptake. Genotype Masusu, Msolini and Kasukamywele showed consistence in yielding both in green house and field. This may indicate the stability behaviour of these genotypes, hence calls for further study to confirm these findings so that these genotypes can be recommended in moisture deficit areas (Fening *et al*., 2009). These genotypes had high shoot biomass which is a major consideration in the choice of crops for their tolerance to moisture stress condition. This trait could be used as an indirect selection criterion for drought resistance. Genotype Kijivu showed high yielding in green house experiment but low in field experiment, this may specify the sensitivity of this genotype to environment. Plant characteristics such as total plant biomass and grain yield have been used to determine superiority for N_2 fixation (Kipe-Nolt and Giller, 1993).

Table 3: Effects of genotype in green house

Genotype	Plant height (cm)	Root length (cm)	Yield (kg/ha)	Shoot biomass (g)	Root biomass (g)	50% flowering	85% maturity
Kijivu	195.5a	17.5c	6.5e	4.5ab	0.23ab	35.5d	56.1a
Yellow	82.3a	12.1ab	3.4bc	3.9ab	0.19a	31.9b	57.4abc
Msolini	199.7c	14.2abc	5.9de	4.7b	0.19a	34.7cd	58.7bcd
Masusu	207.3c	14,1abc	5.9de	4.8b	0.24ab	33.1bc	56.9ab
K'nywele	187.8c	11.9ab	4.9cd	4.6b	0.16a	34.3cd	57.8abc
Uyole 04	135.4b	10.0a	3.0ab	2.7a	0.16a	38.0e	60.3de
Mbulamtwe	101.3a	11.1ab	3.7bc	4.2ab	0.14a	27.9a	56.6ab
Bilfa Uyole	135.4b	10.2a	4.9cd	3.0ab	0.25ab	37.6e	59.6cd
G 51495 A	180.0c	14.9bc	1.9a	4.2ab	0.33b	39.4e	62.1e
Mean	**153.3**	**12.9**	**4.4**	**4.1**	**0.21**	**34.7**	**58.2**
CV%	**27.9**	**7.9**	**16.7**	**25.4**	**19.5**	**8.2**	**4.9**
SE	**10.7**	**1.5**	**0.5**	**0.6**	**0.04**	**0.7**	**0.7**

Different letters within each column indicate significant different at 5% level

Table 4: Effects of genotype in the field

Genotype	Plant height (cm)	Root length (cm)	Yield (g/plant)	Shoot biomass (g)	Root biomass (g)	50% flowering	85% maturity
Kijivu	60.7c	16.3a	58.9ab	31.4abc	1.8a	31.9d	65.00ab
Yellow	46.8ab	16.8a	83.0bc	31.4abc	1.4a	29.4bc	64.3ab
Msolini	96.6e	17.1a	81.8bc	33.2bc	1.3a	31.3cd	67.6bc
Masusu	93.6e	16.3a	94.6c	33.8bc	1.6a	28.0ab	65.3ab
K'nywele	95.2e	15.1a	78.2bc	36.0c	1.6a	28.0ab	67.5bc
Uyole 04	86.2de	15.0a	45.7a	24.7a	1.3a	30.7cd	71.8d
Mbulamtwe	39.0a	14.9a	79.3bc	33.8bc	1.7a	27.4a	62.22a
Bilfa Uyole	76.1d	14.9a	77.4bc	32.7bc	1.7a	34.4e	69.6cd
G 51495 A	54.1bc	18.1a	45.3a	26.6	1.7a	36.3e	70.6cd
Mean	**72.0**	**16.1**	**74.5**	**31.5**	**1.5**	**31.7**	**67.1**
CV%	**4.8**	**4.7**	**12.4**	**3.8**	**19.5**	**7.3**	**5.8**
SE	**4.0**	**1.2**	**9.1**	**2.5**	**0.2**	**0.7**	**1.1**

Different letters within each column indicate significant different at 5% level

3.3 Effects of moisture stress levels

The results from this study showed that moisture stress was a limiting factor for proper agronomic growth and development of plants especially at 25% moisture stress level (Table 5 and 6). Moisture stress is the most important environmental factor resulting in crop yield losses (Marino *et al*., 2007). Emam and Seghatoleslami (2005) reported that moisture stress reduced dry matter production, yield and yield components through reducing leaf area and quickening leaf senesces. Molina *et al*. (2001) reported that water stress reduced grain yield of common bean cultivars by about 50%.

Table 5: Effects of moisture stress levels in green house

Moisture regime %	Plant height (cm)	Root length (cm)	Yield (g/plant)	Shoot biomass (g)	Root biomass (g)	50% flowering	85% maturity
100	157.0b	14.2b	5.0b	4.7b	0.27b	35.2ab	58.4a
75	158.1b	13.4b	4.9b	4.5b	0.22b	35.7b	58.9a
50	165.0b	13.4b	4.8b	3.8b	0.20ab	34.1a	58.3a
25	135.9a	10.3a	2.8a	2.3a	0.10a	34.2a	57.6a
Mean	**153.3**	**12.8**	**4.3**	**4.0**	**0.19**	**34.8**	**58.3**
Se	**6.7**	**0.9**	**0.3**	**0.4**	**0.03**	**0.5**	**0.5**

Different letters within each column indicate significant different at 5% level

Table 6: Effects of moisture stress levels in the field

Moisture regime %	Plant height (cm)	Root length (cm)	Yield (g/plant)	Shoot biomass (g)	Root biomass (g)	50% flowering	85% maturity
100	74.4a	17.6b	87.5b	34.7b	1.68b	32.1a	68.4a
75	73.0a	16.7b	84.9b	33.1b	1.71b	32.4a	66.8a
50	72.7a	16.3b	80.5b	31.9b	1.62b	31.3a	66.6a
25	67.9a	13.7a	45.2a	26.9a	1.19a	31.1a	66.4a
Mean	**72.0**	**16.1**	**74.5**	**31.7**	**1.55**	**31.7**	**66.5**
Se	**2.7**	**0.8**	**6.1**	**1.6**	**0.1**	**0.5**	**0.8**

Different letters within each column indicate significant different at 5% level

3.4 Effects of moisture stress levels and genotype on plant height

There was significant difference ($P \leq 0.05$) among genotypes for plant height due to moisture stress. However, there was no significant effect of the interaction ($P \geq 0.05$) between moisture stress and genotypes. Moisture stress caused differences in plant height in the pot experiments which varied from 230.9 cm for genotype Masusu in 100% moisture regime to 72.5 cm for genotype Mbulamtwe in 25% moisture regime (Table 7). However, the genotypes Masusu, Kijivu, Msolini, Kasukanywele, and G 51495 A gave the highest plant height in almost all moisture stress levels. This may be an indication of superior performance of these genotypes under moisture stress. These results agree with the result of Shenkut and Brick (2003) and Emam *et al*. (2010) who also reported depressed plant height due to moisture stress levels. In the field experiments, plant heights varied from 105 cm for genotype Masusu in 100% moisture regime to 41 cm for Mbulamtwe in 25% moisture regime. Moisture stress has been confirmed to reduce plant growth (Boutraa *et al*., 2010; Beebe *et al*., 2008). Plant height is the morphological features linked with moving the carbohydrates especially under stress condition (Boutraa *et al*., 2010). Hence, decrease in plant height might be due to the reduction in the cell division and cell elongation. Ohashi *et al*. (2000) reported insufficient moisture on the reduction of plant height due to decreased photosynthesis production and translocation to plant parts.

Table 7: Effects of moisture stress on plant height

	Plant height (cm) Greenhouse					**Plant length (cm) Field**				
Genotype	**100%**	**75%**	**50%**	**25%**	**Mean**	**100%**	**75%**	**50%**	**25%**	**Mean**
Kijivu	208.8	199.4	197.1	176.9	**195.6**	63.0	59.0	58.7	62.0	**60.7**
Yellow	84.6	91.0	79.4	74.4	**82.4**	43.7	59.0	42.7	42.0	**46.9**
Msolini	186.2	213.8	230.6	168.2	**168.2**	100.0	97.0	94.0	95.3	**96.6**
Masusu	230.9	174.9	238.6	185.0	**206.7**	105.0	98.2	91.3	82.0	**94.1**
K'nywele	182.6	198.1	214.4	156.2	**187.8**	99.3	106.6	86.7	87.7	**95.1**
Uyole 04	141.2	121.4	167.9	111.2	**135.4**	88.3	79.7	81.0	95.7	**86.2**
Mbulamtwe	100.8	158.7	73.4	72.5	**101.4**	39.7	36.7	38.7	41.0	**39.3**
BilfaUyole	162.5	130.6	135.5	113.1	**135.4**	75.0	79.3	95.0	55.0	**76.1**
G 51495 A	182.8	196.0	168.4	172.8	**180.0**	43.7	71.3	50.3	51.0	**54.1**
Mean	**164.5**	**164.9**	**167.3**	**136.7**		**73.1**	**76.3**	**70.9**	**67.9**	
SE within table 21.4, LSD 59.9						**SE within table 7.9, LSD 22.6**				

3.5 Effects of moisture stress levels and genotype on root length

There was significant difference ($P \leq 0.05$) among genotypes on root length due to moisture stress (Table 8). In this study, root length was generally reduced with increased moisture stress in both pot and field experiments.

Root length varied from 22.9cm in 100% moisture regime (genotype Kijivu) to 6.50cm in 25% moisture regime (genotype yellow) and from 108.4 cm in 100% moisture regime (genotype Bilfa Uyole) to 29.9cm (25% moisture regime in Uyole 04) in pot and field experiment, respectively. Root reduction may reflect the impact of water stress on root cell development which would impair nutrient uptake and affect photosynthesis which is essential for biomass accumulation and thus root elongation (Blum, 2011 and Guo *et al*., 2013).

Table 8: Effect of moisture stress on root length

	Root length (cm) Greenhouse					Root length (cm) Field				
Genotype	**100%**	**75%**	**50%**	**25%**	**Mean**	**100%**	**75%**	**50%**	**25%**	**Mean**
Kijivu	22.9	22.5	14.6	9.9	**17.5**	88.1	61.8	45.0	40.6	**58.9**
Yellow	13.8	13.1	15.0	6.5	**12.1**	103.9	85.7	86.6	56.0	**83.1**
Msolini	15.0	14.4	16.4	10.9	**14.2**	94.7	93.0	86.1	53.4	**81.8**
Masusu	17.0	13.0	15.6	10.9	**14.1**	101.0	133.3	97.7	38.3	**92.6**
K'nywele	13.0	10.9	12.4	11.5	**12.0**	102.9	90.4	73.1	52.3	**79.7**
Uyole 04	9.4	9.0	14.6	7.0	**10.0**	74.2	46.2	32.3	29.9	**45.7**
Mbulamtwe	10.5	12.9	10.9	10.1	**11.1**	86.8	99.2	83.6	47.7	**79.3**
BilfaUyole	13.9	9.8	8.6	8.5	**10.2**	108.4	100.3	68.4	35.7	**80.5**
G 51495 A	18.3	16.3	13.9	11.5	**15.0**	74.2	72.6	88.3	52.4	**71.9**
Mean	**14.9**	**13.5**	**13.6**	**9.6**		**74.2**	**72.6**	**88.3**	**52.4**	

SE within table 2.9, LSD 8.1 **SE within table 2.5, LSD 6.9**

3.6 Effects of moisture stress levels and genotype on grain yields

There was significant difference ($P \leq 0.05$) in grain yield due to moisture stress and genotype. There was also significant effect of the interaction ($P \leq 0.05$) between water stress and genotypes. Grain yields were reduced with increasing moisture stress, both in the greenhouse and in the field, especially at the 25% moisture regime (Table 9). Msolini and Masusu genotypes had higher yields under all stress regimes. Low regime (25%) reduced yields for all genotypes. In the pots, the higher yields were generally obtained for most genotypes in the 100% moisture regime. The genotypes Kijivu, Msolini, Masusu and Bilfa Uyole had the highest yields at 100% moisture regime. In the field, the highest yields in the 100% moisture regime were obtained from BilfaUyole, Yellow and Kasuksnywele and their yields also decreased with increasing moisture stress. This result agrees with the result of Singh, (2007) and Urrea *et al*., (2009) who noted reduced yields due to moisture stress.

On the other hand, Masusu had higher yields in 75% moisture regime than even in the 100% moisture regime, but decreased with increasing moisture stress. The good performance of Masusu in the field, even under reduced moisture (75%) may be an indication of its potential for drought tolerance (Beebe *et al*., 2010 and Fening *et al*., 2009). Thus, such genotypes as Masusu merit further investigation to ascertain this seeming high potential for drought tolerance (Amede *et al*., 2004; King and Purcell, 2006; and Beebe *et al*., 2012). The suppressed performance of Kijivu in the field (as opposed to the greenhouse) may be an indication that Kijivu is not very stable in the field where, usually, moisture conditions fluctuate more with rainfall flactuations.

Shenkut and Brick (2003) and Frahm *et al*. (2004) reported that drought stress has substantial impact on common bean growth and seed yields, though the ranges of reductions were highly variable due to the different genotypes used, as was also observed in the present study. Moisture stress can affect the photosynthesis or may affect nodule metabolism directly (Rosales-Serna *et al*., 2004; Rao *et al*., 2006; and Gebeyehu, 2006), thereby affecting plant growth and yields. The results also showed that the nodulated genotypes had more grain yield than non-nodulated genotype especially under high moisture regimes where the numbers of nodules were high. This difference may be attributed primarily to nitrogen fixation. As it was observed under high moisture stress (25%) where the number of nodules was very low there was no significant difference in grain yield between non-nodulated (G 51495 A) and nodulated genotypes (Beebe *et al*., 2008 and Polania *et al*., 2008). Hence high yield might be used as selection criteria for high nitrogen fixation.

Table 9: Effect of moisture stress on grain yields

	Grain yields (g/plant) Greenhouse					Grain yields (g/plant) Field				
Genotype	**100%**	**75%**	**50%**	**25%**	**Mean**	**100%**	**75%**	**50%**	**25%**	**Mean**
Kijivu	8.9	8.2	6.1	2.9	**6.5**	17.6	12.4	9.0	8.1	**11.8**
Yellow	3.6	4.4	3.0	2.9	**3.5**	20.8	17.1	17.3	11.2	**16.6**
Msolini	7.4	6.2	6.8	3.3	**5.9**	19.0	18.6	17.2	10.7	**16.4**
Masusu	7.0	6.5	6.7	3.6	**6.0**	20.2	26.7	19.5	7.7	**18.5**
K'nywele	5.8	6.2	6.2	1.6	**5.0**	20.6	18.1	14.6	10.5	**16.0**
Uyole 04	4.1	3.5	2.6	1.4	**2.9**	14.9	9.3	6.5	6.0	**6.2**
Mbulamtwe	5.7	3.7	3.5	2.3	**3.8**	17.4	19.8	16.7	9.5	**15.9**
BilfaUyole	6.2	4.5	5.2	4.1	**5.0**	21.7	20.1	13.7	7.2	**15.7**
G 51495 A	1.8	1.8	1.7	2.5	**2.0**	14.8	14.5	17.7	6.3	**13.3**
Mean	**5.6**	**5.0**	**4.6**	**2.7**		**18.6**	**17.4**	**1.7**	**8.6**	

SE within table 0.9, LSD 2.9 **SE within table 18.2, LSD 6.4**

3.7 Effects of moisture stress on shoot biomass

The results showed no significant difference ($P \leq 0.05$) on shoot biomass due to moisture stress and genotypes (Table 10). Generally shoot biomass decreased with increased moisture stress. The shoot dry weight varied from 7.2 g/plant for genotype Mbulamtwe in 100% moisture regime to 1.1 g/plant for genotype Uyole 04 in 25% moisture regime in greenhouse, while in the field it varied from 42.1 g/plant (Kasukanywele) to 20.4 g/plant (G 51495 A). The genotypes Mbulamtwe, Msolini, Kasukanywele and Kijivu had slightly, though not significantly; higher shoot biomass both in the greenhouse and field experiment as compared to the other genotypes at 25% moisture stress. This may indicate the need to further screen these genotypes for ability to accumulate biomass under some moisture stress. Improving plant productivity under moisture stressed environment requires selection for genotypes which accumulate higher biomass (Lopes *et al*., 2011) because biomass and grain yield have a strong positive association (Shenkut and Brick, 2003). King and Purcell (2006) reported that drought reduced biomass accumulation in soybean by 42%. Drought also affected biomass accumulation in mung bean (Thomas *et al*., 2004). This result showed that the non-nodulating (G 51495 A) genotype accumulated about the same shoot biomass as the nodulating genotypes. This indicates that nodule biosynthesis is not the only source of N especially in non-nodulating common bean. Diaz-Leal *et al*., 2012 reported that in non-nodulating common bean remobilized N in older vegetative tissue. Hence indicates that G 51495 A had capacity to absorb and assimilate mineral N efficiently to support biomass accumulation (Kabahuma, 2013).

Table 10: Effect of moisture stress on shoots biomass

	Shoot biomass (g/plant) Field					Shoot biomass (g/plant) Greenhouse				
Genotype	**100%**	**75%**	**50%**	**25%**	**Mean**	**100%**	**75%**	**50%**	**25%**	**Mean**
Kijivu	34.6	34.3	29.4	27.5	**31.5**	5.3	4.8	3.8	4.3	**4.6**
Yellow	35.6	35.5	31.7	22.8	**27.1**	5.1	3.9	3.8	3.1	**4.0**
Msolini	39.8	33.1	29.6	30.5	**33.3**	5.6	4.2	5.2	4.1	**4.8**
Masusu	38.3	38.0	35.3	23.3	**33.7**	4.4	6.2	5.0	3.8	**4.9**
K'nywele	42.1	36.8	34.9	30.7	**36.1**	4.2	4.8	5.7	4.0	**4.7**
Uyole 04	24.5	25.8	24.1	24.3	**24.7**	6.3	1.4	2.4	1.1	**2.8**
Mbulamtwe	41.1	30.7	33.2	30.3	**33.8**	7.2	2.4	3.9	3.5	**4.3**
BilfaUyole	38.0	33.5	31.8	27.6	**32.7**	4.3	2.5	3.3	2.2	**3.1**
G 51495 A	30.0	32.1	23.9	20.4	**26.6**	4.7	4.4	3.9	3.9	**4.2**
Mean	**36.0**	**33.3**	**30.4**	**26.4**		**5.2**	**3.8**	**4.1**	**3.3**	

SE within table 0.2, LSD 14.1 **SE within table 4.9, LSD 3.5**

3.8 Effects of moisture stress levels on root biomass

There was significant difference ($P < 0.01$) due to moisture stress on root biomass and ($P > 0.05$) due to genotypes. However, there was no significant effect of the interaction between moisture stress and genotypes for root biomass (Table 11). The root biomass in greenhouse varied from 0.43 g/plant for genotype G 51495 A in 100% moisture regime to 0.10 g/plant (Mbulamtwe) in 25% moisture regime while in the field they respectively ranged from 2.53 g/plant (G 51495 A) to 0.67 g/plant (Yellow). Genotype G 51495 A a non-nodulating accumulated high root biomass indicating the ability of this genotype to absorb and assimilate mineral N to support biomass accumulation (Kabahuma, 2013). Genotypes G 51495 A and Kijivu had higher root biomass in both experiments; this may indicate that these genotypes had better root development as a drought avoidance mechanism (Blum, 2011), since higher root development can be an adjustment for shoot as well as grain production (Ao *et al*., 2010).

Table 11: Effect of moisture stress on root biomass

	Root biomass (g/plant) Field					Root biomass (g/plant) Greengouse				
Genotype	**100%**	**75%**	**50%**	**25%**	**Mean**	**100%**	**75%**	**50%**	**25%**	**Mean**
Kijivu	2.2	1.0	1.7	1.0	**1.5**	0.3	0.3	0.2	0.2	**0.3**
Yellow	1.9	1.9	1.5	0.7	**1.5**	0.2	0.3	0.2	0.1	**0.2**
Msolini	1.5	1.3	1.3	1.1	**1.3**	0.3	0.1	0.3	0.1	**0.2**
Masusu	2.0	1.0	1.9	0.9	**1.5**	0.4	0.3	0.2	0.1	**0.3**
K'nywele	1.7	1.0	1.2	1.0	**1.2**	0.2	0.2	0.2	0.1	**0.2**
Uyole 04	1.8	1.9	1.4	1.4	**1.5**	0.1	0.1	0.3	0.2	**0.2**
Mbulamtwe	2.4	1.6	1.6	1.2	**1.7**	0.2	0.1	0.2	0.1	**0.2**
BilfaUyole	1.7	1.5	1.3	1.3	**1.5**	0.3	0.3	0.2	0.2	**0.3**
G 51495 A	2.5	1.4	1.1	1.1	**1.5**	0.4	0.4	0.2	0.3	**0.3**
Mean	**2.0**	**1.4**	**1.4**	**1.1**		**0.3**	**0.2**	**0.2**	**0.2**	
SE within table 0.1, LSD 1.2						**SE within table 0.4, LSD 0.2**				

3.9 Reduction Indexes

There was variation among genotypes on the reduction indexes (as percentages) from 100% moisture stress to 25% moisture stress. In green house plant height and root length IR varied from 5.5 - 30.4 and 3.6 - 56.1 respectively (Table 13 and 14). Msolini and G 51495 A had lower IR for plant height while Mbulamtwe and Kasukanywele had lower IR for root length. IR for grain yield varied from 18.8 - 72.3, Yellow genotype had lower IR. The greater value of IR indicates the sensitivity of this trait to moisture stress. The IR for SDW varied from 2.9 - 82.4. Genotype Kasukanywele and Masusu had lower IR while Uyole 04 and Mbulamtwe had the highest. IR for RDW varied from 34.9 - 62.0 the lowest being genotype G 51495 A while the highest was Masusu. Days to 50% flowering had IR ranged from 0 - 11.4, genotypes Kijivu, Kasuksnywele, Uyole 04 and Bilfa-Uyole had 0 IR, while Masusu had higher. Genotypes with low IR% should be taken into consideration as it shows the ability of drought tolerance.

Table 13: Reduction indexes in percentages (IR%) in greenhouse

Genotype	**Plant height (cm)**	**Root length (cm)**	**Grain yield (g)**	**Shoot dry weight (g)**	**Root dry weight (g)**
Kijivu	15.3	56.1	67.6	19.2	50.0
Yellow	12.1	52.7	18.8	39.2	35.0
Msolini	9.7	27.5	55.9	27.0	48.0
Masusu	19.9	36.0	48.3	14.2	62.0
K'nywele	14.5	11.5	72.3	2.9	35.0
Uyole 04	25.9	34.0	65.8	82.4	38.0
Mbulamtwe	28.1	3.6	60.5	51.7	50.0
BilfaUyole	30.4	38.8	34.8	49.5	45.5
G 51495 A	5.5	37.0	26.5	18.9	34.9

Table 14: Reduction indexes in percentages (IR%) in the field

Genotype	**Plant height (cm)**	**Root length (cm)**	**Grain yield (g)**	**Shoot dry weight (g)**	**Root dry weight (g)**
Kijivu	1.6	53.9	53.8	20.5	52.5
Yellow	3.8	46.1	46.1	35.9	65.3
Msolini	4.7	43.6	43.6	23.4	23.1
Masusu	21.9	62.1	37.8	39.2	53.0
K'nywele	11.7	49.2	49.2	27.0	37.6
Uyole 04	8.3	59.7	59.7	0.7	23.5
Mbulamtwe	3.4	45.1	45.1	26.3	49.4
BilfaUyole	26.7	67.0	67.0	27.3	20.4
G 51495 A	16.8	29.4	57.5	31.9	57.7

PH: Plant height (cm), RL: Root length (cm), GY: Grain yield (g), SDW: Shoot dry weight (g), RDW: Root dry weight, 50%: Days to 50% flowering, 85%: Days to 85% maturity

4.0 Conclusions

From the results of this study, moisture stress had a substantial impact on the general performance of the common bean genotypes. These results suggest that common beans are highly sensitive to moisture stress. Genotypes Msolini, Masusu, Yellow and Bilfa-Uyole still had yields under moisture stress. These genotypes can be considered to have some degree of drought tolerance; hence further studies should be conducted using these genotypes. Selection of superior performing genotypes under moisture stress, and integrating them into the breeding programs for drought tolerance is important to increase crop productivity.

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