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EFFECT OF LEVELS AND TIMING OF APPLICATION OF GIBBERELLIC ACID ON GROWTH AND YIELD COMPONENTS OF COMMON BEANS

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ABSTRACT

This study was conducted to determine the effect of levels and timing of application of gibberellic acid (GA_3) on growth and yield components of common beans (*Phaseolus vulgaris* L.). Experiments were conducted at the Field Station Farm at the Faculty of Agriculture, University of Nairobi, Kenya during 1997 and 1998. "Mwezi moja" bean cultivar was used in study. Gibberellic acid (GA_3) was sprayed at 0, 2.5, 5.0 and 7.5 mg l^{-1} to whole bean plants at 7, 14 or 28 days after emergence (DAE). The effect of GA_3 and timing of application on growth, yield and yield components was significant ($P \leq 0.05$). Applications of GA_3 led to increased plant height, leaf area index (LAI), fractional solar radiation interception, root, shoot and the total dry mass. It also increased yield per plant, pods per plant, 100-seed mass and harvest index. The highest seed yields were equivallent to 1854 kg ha^{-1} in 1997 and 5890 kg ha^{-1} in 1998. These yields are high as compared to average national yields of 500 kg ha^{-1}. Significant differences in the parameters measured were generally observed at 14 DAE in GA_3 treated plants.

Key Words: Growth regulators, Kenya, legumes, *Phaseolus vulgaris*

RÉSUMÉ

Cette étude était conduite pour déterminer les effets des doses et le moment d'application de l'acide gibberellique (GA_3) sur la croissance et les composantes de rendement de l'haricot commun (*Phraseolus vulgaris* L.). Les expériences étaient conduites dans les champs de la station agricole de la Faculté de l'Agriculture, Université de Naïrobi-Kenya entre 1997 et 1998. La variété « mwezi moja » était utilisée dans cette étude. L'acide gibberellique était appliquée à des doses de 0, 2.5, 5.0 et 7.5 mg L^{-1} à toute les plantes de haricots à 7, 14 ou 28 jours après l'émergence (DAE). Les effets de GA_3 et le temps d'application sur la croissance, le rendement et les composantes du rendement étaient significatifs ($P<0.05$). L'application de GA_3 entraina l'augmentation de la taille des plantes, indice de surface des feuilles, la fraction de l'énergie solaire interceptée, les racines, shoot et la masse total de la matière sèche. Elle entraina aussi l'augmentation du rendement par plante, gousse par plante, la masse de 100 graines et l'indice de la récolte. Les rendements les plus élévés étaient équivalents à 1854 kg ha^{-1} en 1997 et 5890 kg ha^{-1} en 1998. Ces valeurs de rendements sont élévées par rapport à la myenne nationale de 500 kg ha^{-1}. Des différences significatives concernant les paramètres mesurés étaient généralement observées à 14 jours après émergence dans les plantes traitées au GA_3.

Mots Clés: Régulateurs de la croissance, Kenya, légumes, *Phaseoulus vulgaris*

INTRODUCTION

Legume genotypes with fast early growth rates during early plant growth and development tend to have high dry mass accumulation and seed yield (Laing *et al.*, 1984). Dry matter accumulation in common bean (*Phaseolus vulgaris* L.) is achieved through establishment of a substantial leaf area index (LAI) that is durable throughout the reproductive phase of a plant (Mburu, 1996). Earlier studies reveal that high dry matter accumulation in crops can be enhanced through selection of suitable genotypes, application of adequate nitrogen and effective irrigation (Mburu, 1996). Elsewhere, application of exogenous plant growth regulators (PGRs) such as gibberellic acid (GA_3) to stimulate dry matter accumulation and hence increase yield gains has been exploited with appreciable success (Gardner *et al.*, 1985) has not been explored in Africa.

High level GA_3 application ($\geq$10 mg l^{-1}) increases plant height in broad beans (*Vicia faba*) (Abdul and Said, 1984), pigeon peas (*Cajanus cajan*) (Daykin *et al.*, 1997) and common beans (Abdel-Fattah *et al.*, 1995). In addition, it increases the number of leaves per plant, LAI, leaf area duration, root and shoot fresh weights (Harb, 1992), and plant dry mass (Shaddad and El Tayeb, 1990) of many legumes. In pigeon pea (*Cajanus cajan* L.) (Singh *et al.*, 1978), and broad beans (Diethelm *et al.*, 1986), high application of GA_3 led to increase in podset, number of fruit bearing nodes, pod weight and seed yield. Abdel-Fattah *et al.* (1995) reported increased seed number and seed yields in common beans upon application of GA_3 just before flowering. These observations were obtained after a single application of GA_3 during the growth period, especially before flowering. There is a possibility therefore that this rate and timing of application is not the optimum, yet the influence of lower levels and time of application of GA_3 in common beans has not been investigated. This study was, therefore, undertaken to determine the effect of application of low to moderate levels of GA_3 at different times of application on the growth, yield and yield components of common beans.

MATERIALS AND METHODS

The common bean cultivar "Mwezi moja" obtained from Kenya Seed Company was used in this study. Field experiments were conducted at the University of Nairobi Field Station Farm, at Kabete Campus, during the short rains of 1997 (1997B) and long rains of 1998 (1998A). The site is located at 1°15 South and 36°44 East; at an altitude of 1942 m (Mburu, 1996). The area has an annual mean temperature of 18° C, with the mean monthly temperatures varying between 14° C in June and 24° C in February.

The area receives bimodal rainfall with an annual mean of 1000 mm, with peaks in November and April, separated by a cool dry spell from June to September. Approximately 57% of the precipitation is received during the long rains. Site soil is Humic Nitosol with some kaolinitic clay minerals (Jaetzold and Schmidt, 1983). The soil is deep, well drained friable clay, dark reddish brown to dark brown (Mburu, 1996). Before establishing the trials during both seasons, soil pH was determined. Nitrogen was determined by the Kjedahl method (Rasmussen and Rohde, 1991).

The study treatments were laid out in a randomised complete block design with three replications in a split plot arrangement. Time of application of GA_3 (at 7, 14 and 28 days after emergence(DAE) formed the main plots, while GA_3 levels were the sub-plots. Gibberellic acid (GA_3) was applied at 0, 2.5, 5.0 or 7.5 mg l^{-1}.

Each sub-plot measured 3 m x 3 m with the furrows spaced at 0.30 m apart. Diammonium phosphate (DAP) fertiliser was broadcast to provide the recommended rates of 25, 64 and 0 kg of N, P and K ha^{-1}, respectively, and incorporated before sowing. Beans were hand seeded in rows at a spacing of 0.15 m and a depth of 0.03 m. Average crop emergence was 85.5% and 83% in 1997B and 1998A, respectively. Insect pests were controlled by spraying with dimethoate (1ml l^{-1}). Gibberellic acid was applied using a hand sprayer in the morning between 0800 and 1000-h (local time) in order to reduce photo effects.

Plant height and leaf area index (LAI) were measured at 22, 32 and 57 DAE. Fractional solar radiation measurements were made at 16, 21, 47, 53 and 59 DAE. The beans were harvested for total, root and shoot dry mass at 22, 32, 57 and 92 DAE. They were hand-harvested from the middle three rows of the sub-plots.

Plant height was determined on four plants in 1997B and three plants in 1998A, randomly chosen in every plot. Measurements were made using a meter rule.

Leaf area index was determined on ten fully expanded leaves selected from a sample of three bean plants randomly selected from each sub-plot. Measurements of LAI were done using the specific leaf area method (Nórman and Campbell, 1994). Using a cork borer, fourty, 0.01 m diameter discs were excised from the leaves. The leaf discs and the remaining leaf portions were separately put into 0.164 m X 0.164 m envelopes and dried at 66°C. After 72 h, dry of the discs (LWdiscs) and the leaf portions (LWleaf) were measured. The LAI was calculated using the following formulae:

LAI= [(LW X (LAdiscs /Lwdiscs)) /3] X N
Where LW = LWdiscs + Lwleaf (total leaf dry mass),
LAdiscs = Leaf area (m^2) of excised leaf discs, and
N = Number of plants (m^{-2}).

Solar radiation interception was measured using a Sunfleck ceptometer (SF 80 Decagon, Pulman, Washington) placed perpendicular to the rows of beans, only in 1998A. Two readings of the intensity of radiation above the ground (RAG) and five readings below the ground (RBG) were taken. Fractional solar radiation interception was calculated using:

Fractional solar radiation interception (%) = [(RAG-RBG)/ RAG] X 100.

Total, shoot and root dry mass were determined on three randomly selected plants in every sub-plot. Immediately after harvesting, the plants were separated into root and shoot portions before oven drying at 66°C for 72 h.

Ten randomly selected plants per plot were finally harvested at physiological maturity (92 DAE). Total seed yield, number of pods and seeds per plant were determined. The number of seeds per pod was calculated from the ratio of the number of seeds per plant to the number of pods per plant.

One hundred-seed mass was determined from the masses of three batches of 100 seeds from each sub-plot. Seed mass was determined after drying at 66 °C for 72 h. The harvest index of three plants per plot was calculated using:

Harvest index = Total seed yield (g)/ Total dry mass (g).

The data obtained were subjected to analysis of variance using SYSTAT (Wilkinson *et al.*, 1992) computer software package. Comparison among significant treatment means was done using the protected least significant difference (LSD (P = 0.05) (Steel *et al.*, 1997). Single-degree polynomial contrasts were fitted using the means of various treatments for trend analysis.

RESULTS

Soil pH (H_2O) determined during the experiments was 6.24 and 6.39 (H_2O) in the short and long rains, respectively. Total N was 0.25% in the short rains and 0.26% in the long rains.

There were no seasonal differences, therefore, pooled data are presented (Steel *et al.*, 1997). Plant height differed significantly ($P \leq 0.05$) for different application times (Fig. 1). The response to increasing GA_3 levels was linear.

Leaf area index also differed significantly ($P \leq 0.05$) following GA_3 application at different times (Fig. 2). Except at 57 DAE in plants treated at 7 DAE, LAI increased with GA_3 levels at all stages of growth for all application times. The response to GA_3 levels was also linear. For plants treated with 7.5 and 5 mg l^{-1} GA_3 at 7 DAE, there was no significant difference in LAI at 57 DAE. Leaf area index increased up to 32 DAE, but decreased by 57 DAE in all treatments. Overall, beans that received GA_3 at 14 DAE showed the highest LAI.

Increasing GA_3 levels led to increased fractional solar radiation interception at all stages of growth and all times of application (Fig. 3). The interception increased and attained maximum values at 46 DAE before decreasing.

Total dry mass differed significantly ($P < 0.05$) among GA_3 levels and the different times of application (Fig. 4). In all treatments, total dry mass increased with time of growth and GA_3 levels. Generally, the increase was greatest after 57 DAE.

Root dry mass also differed significantly ($P < 0.05$) among GA_3 levels and times of application (Fig. 5). Root dry mass increased with time of growth up to 57 DAE then decreased thereafter. Following application at 7 and 14 DAE, increasing GA_3 levels led to increase in root dry mass at only 22, 32 and 57 DAE but not at 92 DAE. Root dry

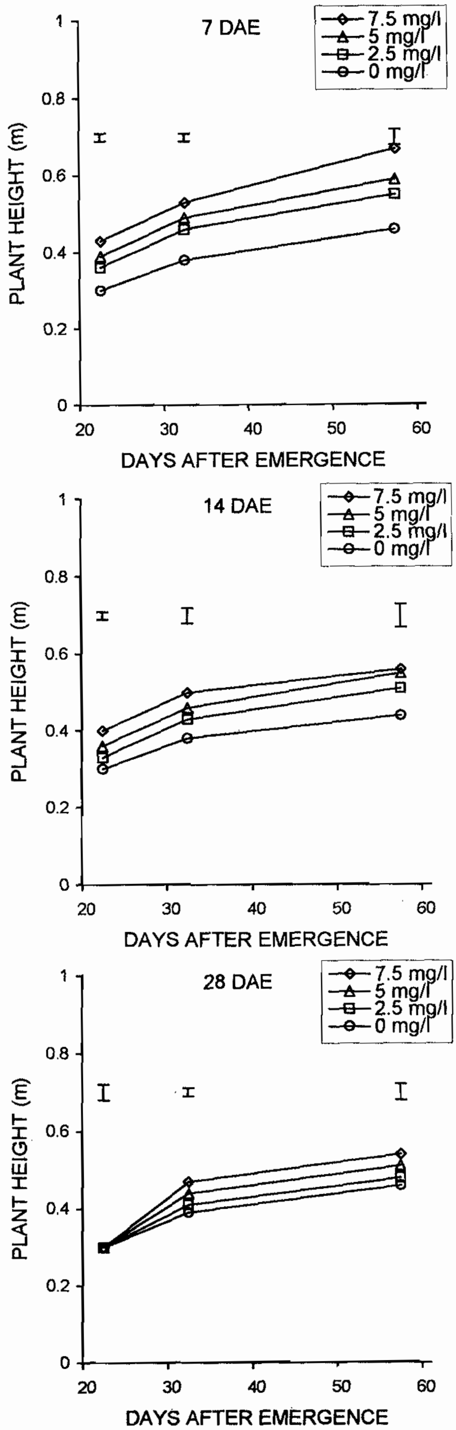

Figure 1. Effect of levels and timing of application of GA_3 on plant height of common beans. DAE = days after emergence. Vertical bars are $LSD_{(0.05)}$ bars.

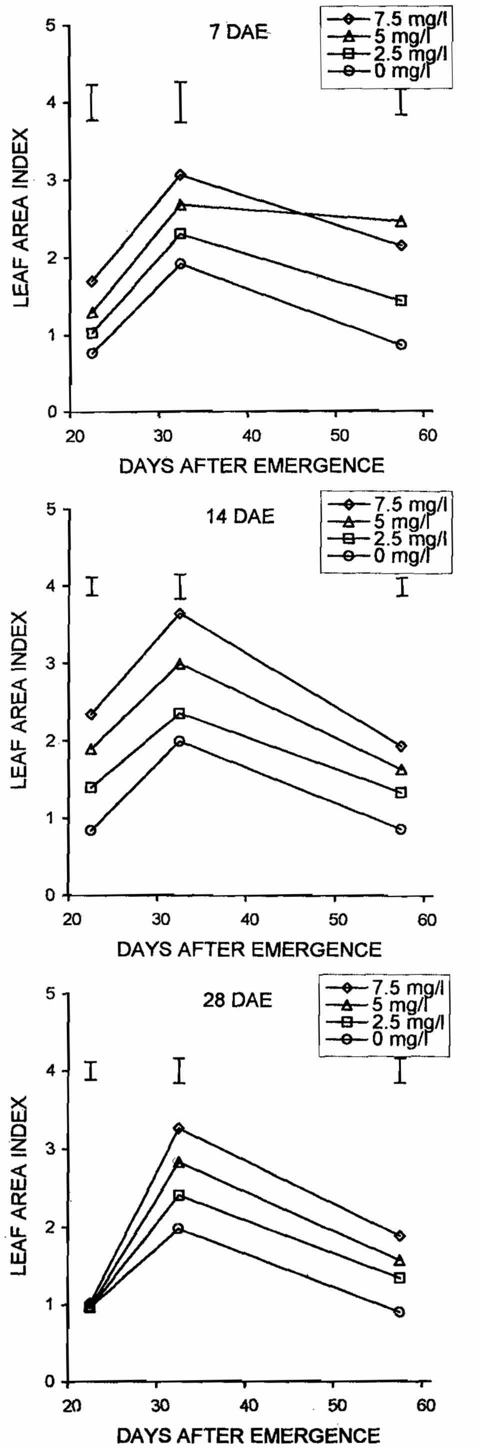

Figure 2. Effect of levels and timing of application of GA_3 on leaf area index of common beans. DAE = days after emergence. Vertical bars are $LSD_{(0.05)}$ bars.

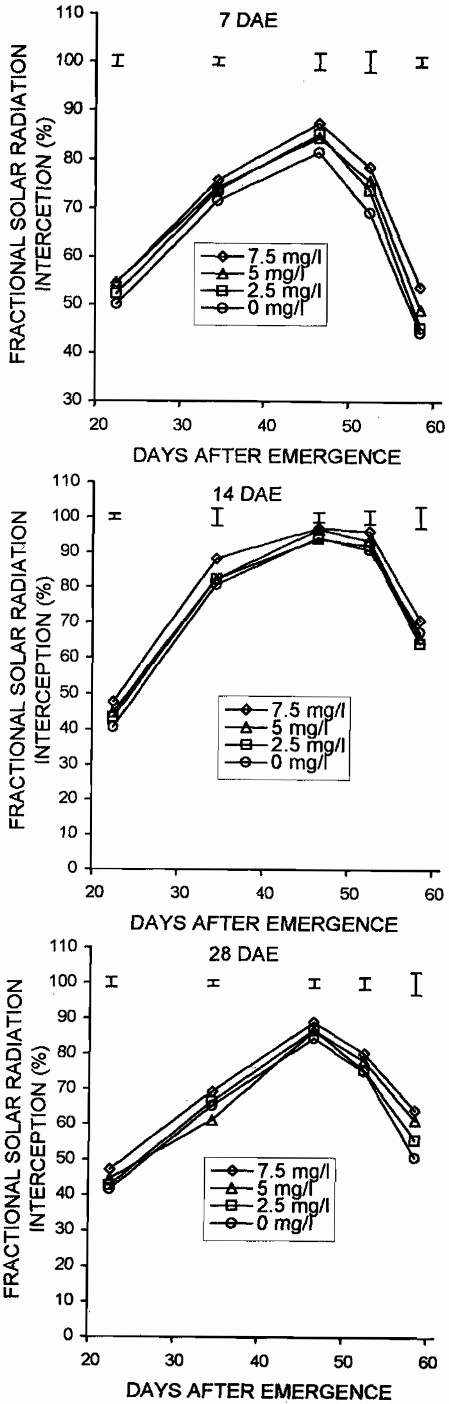

Figure 3. Effect of levels and timing of application of GA_3 on fractional solar radiation interception of common beans. DAE = days after emergence. Vertical bars are $LSD_{(0.05)}$ bars.

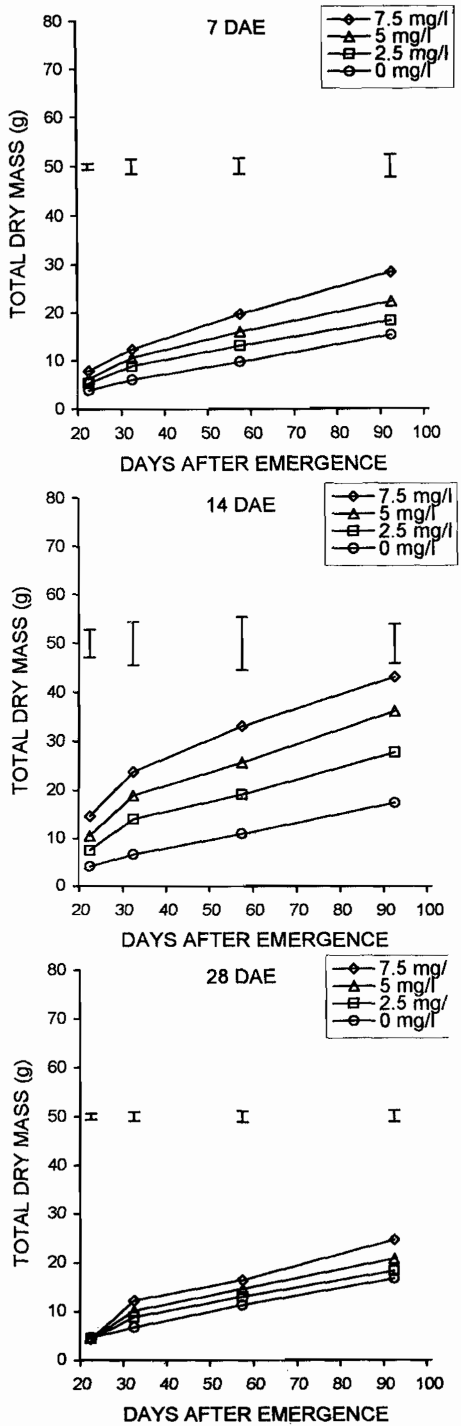

Figure 4. Effect of levels and timing of application of GA_3 on total dry mass of common beans. DAE = days after emergence. Vertical bars are $LSD_{(0.05)}$ bars.

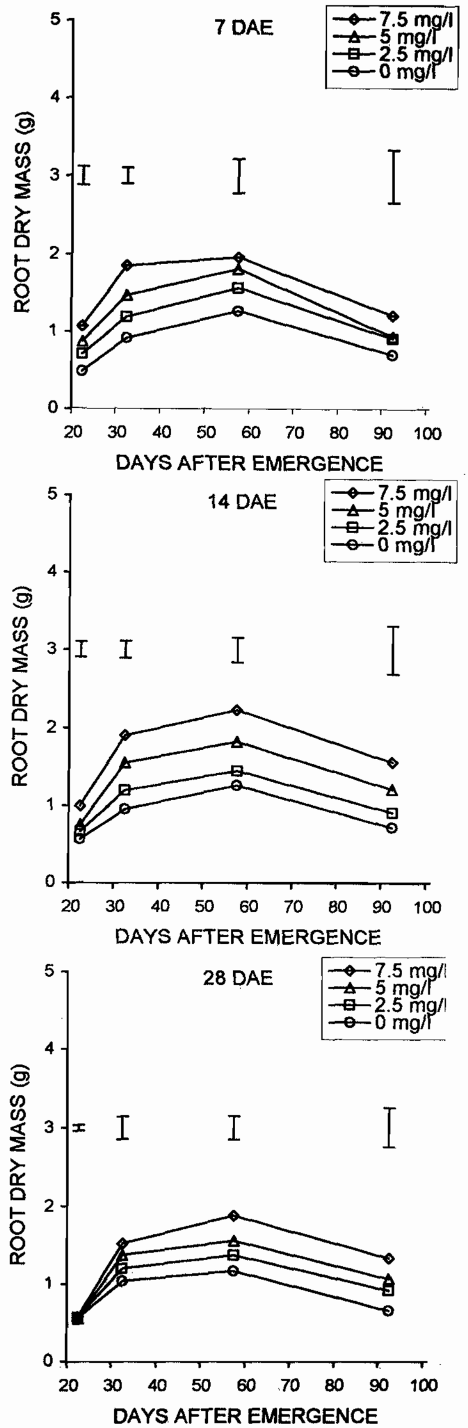

Figure 5. Effect of levels and timing of application of GA_3 on root dry mass of common beans. DAE = days after emergence. Vertical bars are $LSD_{(0.05)}$ bars.

mass only increased with GA_3 levels at only 57 DAE but not at other growth stages after application at 28 DAE. The highest root dry mass was recorded at 14 DAE of GA_3 application.

Shoot dry mass also varied significantly ($P < 0.05$) among GA_3 levels and times of application (Fig. 6). In all treatments, shoot dry mass increased with time of growth and GA_3 levels. Overall, the differences in shoot dry mass due to GA_3 applications were greatest after 57 DAE. The highest shoot dry mass production was recorded at 14 DAE of GA_3 application.

Seed yield per plant increased with GA_3 levels (Table 1). Beans that received GA_3 at 14 DAE had the highest increase in seed yield per plant. The increase was about thrice at 7.5 mg l^{-1} GA_3 compared to the control.

Increasing GA_3 levels led to a linear increase in the number of pods per plant following GA_3 application at different times (7, 14 and 28 DAE) (Table 1). The highest number of pods per plant was also recorded in beans that received GA_3 at 14 DAE.

In contrast, the number of seeds per pod was not significantly ($P>0.05$) affected by level and time of application of GA_3 (Table 1).

Increase in GA_3 levels led to an increase in 100-seed mass at all application times (Table 1). Generally, the highest increases were recorded treatments applied at 14 DAE.

Harvest index significantly ($P < 0.05$) increased with GA_3 levels following application at 14 DAE. However, application of GA_3 at 7 and 28 DAE had no significant ($P>0.05$) effect on harvest index.

DISCUSSION

This study showed that increasing GA_3 levels (0, 2.5, 5.0, 7.5 mg l^{-1}) increases plant height of beans. Similar results have been reported in beans (El- Fouly *et al.*, 1988; Abdel-Fattah *et al.*, 1995) and in many legumes (Gardner *et al.*, 1985; Daykin *et al.*, 1997). Gibberellic acid is known to promote plant growth through stimulation of cell division, cell expansion and cell-wall elasticity (Salisbury and Ross, 1992) and this manifests in the form of plant height.

Gibberellic acid application at 7 and 14 DAE increased LAI and the effect was most pronounced in 14 DAE treated plants. Similar results have

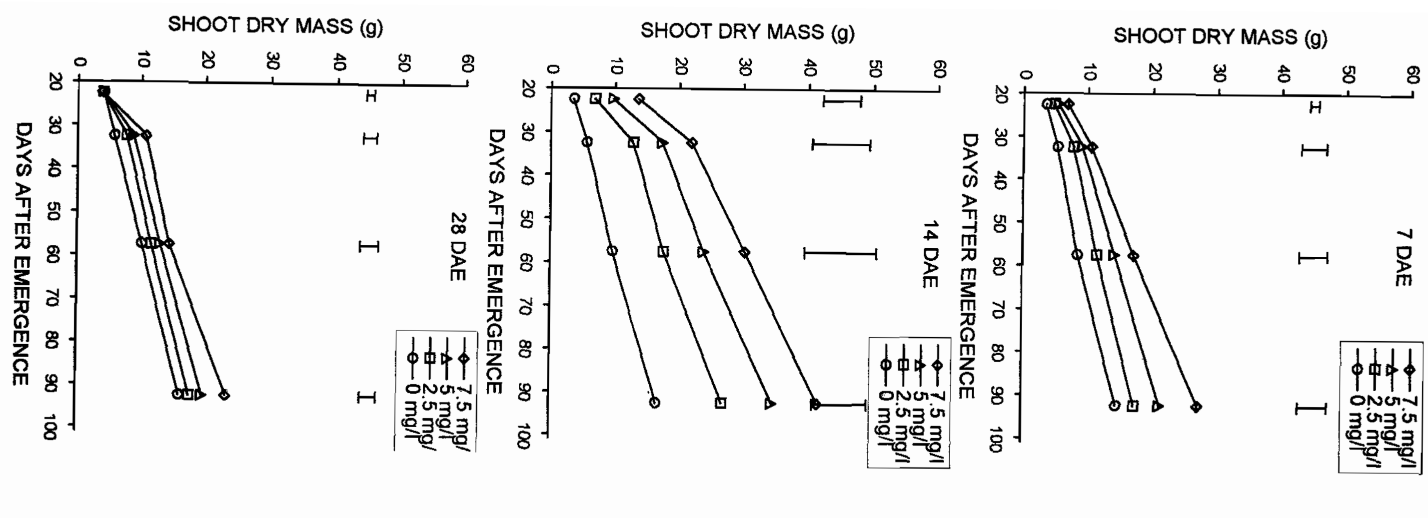

Figure 6. Effect of levels and timing of application of GA_3 on shoot dry mass of common beans. DAE = days after emergence. Vertical bars are $LSD_{(0.05)}$ bars.

TABLE 1. *Effect of levels and timing of application of* GA_3 on bean seed yield and number of pods per plant, number of seeds per pod, 100-seed mass and harvest index

GA_3 Mgl^{-1}	Seed plant^{-1} (g)			Pods plant^{-1}			Seeds pod^{-1}			100-seed mass (g)			Harvest index		
	7 DAE	14 DAE	28 DAE	7 DAE	14 DAE	28 DAE	7 DAE	14 DAE	28 DAE	7 DAE	14 DAE	28 DAE	7 DAE	14 DAE	28 DAE
0	7.20	7.59	7.58	5.53	5.13	5.50	3.51	3.43	3.25	39.80	40.07	40.12	0.50	0.44	0.45
2.5	8.88	13.47	8.9	6.54	8.09	6.37	3.44	3.25	3.30	40.98	42.15	41.02	0.52	0.50	0.51
5.0	11.04	17.08	8.38	7.33	8.99	7.65	3.38	3.21	3.22	42.01	44.02	42.98	0.53	0.49	0.53
7.5	13.76	20.86	13.03	8.00	10.82	8.72	3.29	3.42	3.17	42.69	47.03	44.05	0.51	0.51	0.53
Significance	L*	L,Q	L,Q	L	L	L	NS	NS	NS	L	L,Q	L	NS	L	NS
LSD*GA_3	2.13	4.31	1.32	1.96	2.02	1.24	1.23	1.20	0.87	1.00	1.06	0.78	0.92	0.04	0.09
LSD (DAE)		0.03			0.07			0.01			0.01			0.001	
LSD (GA_3X DAE)		1.08			1.91			0.58			0.41			0.03	

DAE = days after emergence, L = Linear, Q = Quadratic, and NS = not significant, * = significant at $P \leq 0.05$

been reported (Castro and Bergemann, 1976; Harb, 1992). Abdul and Said (1984) and Castro and Bergemann (1976) suggested that GA_3 operated by increasing both leaf number and expansion. A similar effect may have occurred in this study. Our results also showed that late application of GA_3 (28 DAE) does not increase LAI. It is possible that late application of GA_3 does not aid in cell division and expansion, and hence its attendant leaf area increase.

High LAI reportedly leads to greater carbon dioxide fixation by providing greater leaf surfaces exposure to sunlight (Gardner *et al.*, 1985). Conversely, plants with low LAI fix less carbon dioxide. In this study, increase in GA_3 levels led to increased fractional solar radiation interception at all times of application. Hence, more carbon dioxide fixation may have occurred. This interference is colloborated by the corresponding increases in total root and shoot dry mass. This suggests that the benefits of increased LAI were realised immediately through increased plant growth. Owing to less increase in dry mass observed in beans receiving GA_3 at 7 or 28 DAE, it is suggested that GA_3 should be applied at the time of maximum leaf expansion at 14 DAE.

Seed yield per plant also responded to GA_3 levels at times of application in a manner similar to that of plant height, LAI and root and shoot dry matter production. The highest value was 20.86 g (equivalent to 3, 872 kg ha^{-1}) (Table 1). This was higher than the national average bean yields of 500 kg ha^{-1} in Kenya (Jaetzold and Schmidt, 1983). The increase in number of pods per plant and in 100-seed mass could be attributed to better performance of the parameters responsible for the overall grain yield increases. High levels of GA_3 (>10 mgl^{-1}) have been shown elsewhere, to improve seed yields of many legumes (Diethelm *et al.*, 1986; Eid *et al.*, 1992; Abdel-Fattah *et al.*, 1995). The yield increases are likely to have been due to improvement in flowering (Castrol and Bergemann, 1976; Abdel-Fattah *et al.*, 1995), podset (Singh *et al.*, 1978) and seeds mass (Abdel-Fattah *et al.*, 1995). In the present study, the increase in seed yield could be accounted for by GA_3's effect on podset, 100-seed mass, increased carbon fixation due to GA_3 induced increase in LAI, resulting in increased plant dry matter (shoot and roots). Increase in growth and development leads to increase in shoot or total dry mass, resulting in increased flowering, podset, and seed mass. This pattern has been observed in many legumes following high levels of GA_3 application (Singh *et al.*, 1978).

The increase in harvest index resulting from GA_3 application was observed only in plants following application at 14 DAE. Application of GA_3 at 7 and 14 DAE did not significantly ($P \geq 0.05$) affect harves index. Harvest index has been used to indicate translocation of photo-assimilates from other plant parts to the seed (Child and Yang, 1991). Plants with high harvest index exhibit high. This translocation rates largely from roots, shoots and leaves (Gardner *et al.*, 1985) towards the seeds. This study has demonstrated that common bean yield can be significantly increased through administration of GA_3. This effect arises from GA_3's positive effect on plant growth parameters.

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