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Interaction Effect of Growth Regulators and Irrigation Schedules on Growth and Yield of French Beans in Kiambu County, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author ILK designed the study and wrote the first draft of the manuscript with the help of author WNW. Authors JGO, WNW and NKK reviewed the study design and all drafts of the manuscript. Authors NKK and WNW managed the analyses. Authors ILK and JGO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Inadequate and unreliable rainfall distribution in Kenya has affected negatively agricultural yields and family incomes. Integration of growth regulators can stimulate favorable crop growth under limited moisture, but there has been scarce research and documentation on them. Therefore the gibberellic acid and cytokine in effect on French beans growth and yield was assessed under different irrigation schedules at Kenyatta University Field Station in two seasons of 2014/2015. The experiment was set in Randomized Complete Block Design (RCBD) in split-plot arrangement with three levels of each hormone as sub-plots and three watering regimes as main plots and replicated three times. The results showed that optimum rates of growth regulators positively improved the growth and yield components of French beans. Significant differences between the treatments at P<0.05 were observed on the leaf area where the 0.50ml level of cytokine in had the greatest at

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week nine after sowing with 1335.3 cm^2 during the first season and 1343.1 cm^2 during the second season at a daily watering regime. Consequently, this led to significantly the highest pod fresh yield of the French beans with 58.97 g/plant and 84.99 g/plant for the first and second seasons respectively at week nine in the same treatment combination. The highest level of gibberellic acid (0.675 ml) led to the lowest fresh pod yields at week six, seven and eight, while the highest rate of cytokine in (0.750 ml) had the least fresh pod yield at week nine showing the negative effect of excessive application of growth regulators on French beans, yield components. The study, therefore, recommends an application of cytokinin at a rate of 0.50ml to achieve maximum yields in French beans.

Keywords: Growth regulators; French beans; cytokinins; gibberellic acid; pod yield.

1. INTRODUCTION

French beans (*Phaseolus vulgaris*) are a significant vegetable export in Kenya and a potential income earner to small-scale farmers. Smallholder farmers grow most of the crop, and virtually all are exported to Europe. The annual export from fresh vegetables fetches about 35-40% of foreign exchange in Kenya [1]. French bean ranks second after cut flowers in volume and value among export crops [2] accounting 29% (KShs. 4 billion) of the total national earning from fresh vegetable export of KShs. 13.7 billion, in the year 2012 [3]. However, there is a trend in decrease of French bean export figures wherein 2000 French bean export was 25,222 tonnes but in 2001 the amount decreased to 15,407 tonnes, a decrease of about 38.9% [4].

In order to improve productivity and eventually export of the crop it is important to identify production constraints. Water stress is one the major abiotic stress factors that affect the production of the crop in Kenya ranging from moderate and short duration, to extremely severe and prolonged drought. French bean plants are relatively more sensitive to environmental stresses that may occur in the field, compared to most vegetable crops, which negatively affects its growth, yield and even the quality of pods. Field irrigation requirements to achieve maximum yields in vegetable crops are highly dependent on the active root zone where water and nutrients are absorbed [5]. Subsequently, the more occupied soil by roots the more efficient water use, unfortunately most vegetable crops are of shallow root systems including legume crops and their abilities to adapt with moisture changes are poor, particularly at latter stages of growth where pod swelling and seed fillings are synchronized with such moisture changes which resulted in drastic reductions in yield quality and quantity [6].

The use of Plant Growth Regulators (PGR), as gibberellins and cytokinins or their synthetic compounds, is becoming popular to ensure efficient production of crops under water-stress conditions. PGRs modifies growth and development in various ways under normal and stress environmental conditions [7]. Gibberellic acid is one of the most important growth stimulating substances used for promoting cell elongation, cell division and thus to promote growth and development of many plant species. Gibberellic Acids are naturally occurring plant hormones and plants produce them in low amounts [8,9]. Cytokinins (CK) are known to stimulate or inhibit a great number of physiological processes. These hormones have potent effects on plant physiology and are intimately involved in the regulation of cell division, apical dominance, chloroplast development, anthocyanin production and maintenance of the source-sink relationship. In addition, cytokinins are regarded as the most important senescence-retarding hormones and their exogenous application has been demonstrated to prevent the degradation of chlorophyll and photosynthetic proteins as well as reverse leaf and fruit abscission. The response of plants to PGRs may vary with species, varieties, environmental conditions, physiological and nutritional status, stage of development and endogenous hormonal balance [7]. There is little farming of French beans in the country due to insufficient rain water and limited natural water resources and the high potential for French beans production has not been fully exploited. In order to attain this potential, water use efficiency is fundamental through controlled irrigation and application of growth regulators whereby currently there is insufficient information and limited research on their interactions. Therefore this experiment was conducted to evaluate the interactive effect of growth regulators and irrigation on the growth and yield of French beans in Kenya.

2. MATERIALS AND METHODS

2.1 Study Area

The experiments were carried out during the growing seasons of 2014 (June to September) and 2015 (January to March) at the Research Field of the Agricultural Science and Technology Department, School of Agriculture and Enterprise Development, Kenyatta University located at Latitude 1º10'50" S and Longitude 36º55'41" E with an elevation of 1795 m above sea level. The site receives an annual average rainfall of 797 mm with average temperature of 19.5ºC. The total soil N of the site was 0.05% and P was 8 ppm while the soils were found to be moderately acidic (pH 5.89).

2.2 Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) in split-plot arrangement. The hormones as sub-plots had three levels: 0.225 ml, 0.450 ml, and 0.675 ml of gibberellic acid and 0.225 ml, 0.50 ml, and 0.750 ml of cytokinin. The irrigation frequencies as main plots were: irrigating plants every day (irrigation schedule 1); irrigating plants after every two days (irrigation schedule 2); and irrigating plants after every three days (irrigation schedule 3). The rates of each individual application were foliarly sprayed using a back-pack sprayer system consisting of a hand-held boom with nozzles space at 0.5 m apart. The treatments were then replicated three times. The plant growth regulators were sourced from the Kiambu Agro-Chemical Store and the rates were based on the recommended rates by Mervat [10] while the irrigation schedules were based on the Gravimetric method in analysis of soil moisture for French beans and calibrated through the drip line as per the treatments. Application of plant growth regulators was commenced at six weeks after crop emergence through foliar spray. No foliar spray (0 ml) was the control in the experiment.

2.3 Cultural Operations

The French beans seeds (Serengeti variety) was sourced from Royal Seed Company Limited-Nairobi and planted at a rate of two seeds per hole and after crop establishment thinning was done to one plant per hole. The spacing was 30 cm inter row and 15 cm intra row. Di-ammonium Phosphate (DAP) fertilizer was applied at the planting time at the rate of 10 grams per hole. All other agronomic practices were undertaken as recommended.

2.4 Data Collection and Analysis

Plants were sampled and harvested after six weeks at a 1-week interval until the final harvest. At each sampling, 5 adjacent plants in two rows of each plot were taken to the laboratory for trait measurements. Leaf area per plant was determined with a leaf area meter Delta T Device model while the pod weight was weighed using an Avery Digital scale for every plot and averaged per plant by dividing by the stand count. The data collected was refined, tabulated and subjected to Two-Way Analysis Of Variance (ANOVA) using Statistical Analysis System (SAS) to test significance. The means were separated using Fisher's Least Significance Difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Leaf Area

Leaf area had an increasing trend from the first week of sampling through to the last week. The greatest leaf area was observed during week nine after sowing for both seasons. The daily watering interval with 0.50 ml cytokinins showing significantly ($P<0.05$) the largest leaf area of 1335.3 cm^2 and 1345.1 cm^2 during the first and second seasons respectively (Table 1). All the other weeks revealed significant interactions between the growth regulators and watering regimes as well. During week six, the watering interval of one day and all the rates of cytokinin and gibberellic acid at 0.225ml level showed the greatest leaf area. However, the highest rate of cytokinin showed the least leaf area as the watering interval widened. Plant Growth Regulators (PGRs) are known to influence plant growth and development in low concentrations but inhibit plant growth in high concentrations [11]. At week seven, 0.50ml of cytokinin and a one day watering regime elicited the greatest leaf area for both seasons and the control for gibberellic acid and a three-day watering regime had the least. The same trend as week seven was observed in week eight but with also a two day watering regime showing highest leaf area on the same hormone and level.

Table 1. Effect of interaction between irrigation schedules and growth regulators on the leaf area per plant (cm^2) of French beans

Irrigation schedule	Hormone treatments	Week 6		Week 7		Week 8		Week 9	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
1	GA_0	303.33c	311.58b	352.67c	362.96d	473.00d	483.00d	710.67d	716.07c
1	GA_1	341.33a	351.73a	499.62b	509.52b	653.67b	663.53c	912.67a	922.65a
1	GA_2	311.26b	319.46b	362.14c	372.64d	573.36b	583.36b	817.92b	827.02b
1	GA_3	302.67c	312.87b	297.33d	395.13d	434.00d	444.00e	681.00d	689.34d
1	CK_0	289.03c	299.23b	388.08c	398.93d	578.69b	587.09b	1175.14a	1183.44a
1	CK_1	350.76a	359.87a	501.63b	510.69b	765.35b	773.75b	1222.91a	1230.01a
1	CK_2	354.00a	444.08a	862.00a	872.00a	878.67a	885.47a	1335.33a	1343.08a
1	CK_3	351.03a	359.31a	531.08a	541.67b	735.19b	784.91b	1044.14a	1052.54a
2	GA_0	210.21d	219.21d	322.30c	332.73e	355.46e	363.63f	703.45d	546.75e
2	GA_1	230.76d	238.82c	494.63b	502.33b	627.86c	635.86c	837.41b	846.31b
2	GA_2	214.00d	294.09b	321.33c	329.55e	549.00c	529.09c	767.00c	757.54c
2	GA_3	171.00e	179.87e	260.33e	270.33f	359.00f	449.86e	646.67e	554.67e
2	CK_0	156.53e	166.63b	367.00c	347.98e	482.69d	489.69d	520.14f	528.41f
2	CK_1	185.67e	193.67e	424.67b	433.47c	750.33b	758.33b	1005.67a	1013.79a
2	CK_2	192.67e	201.67d	541.00a	631.00a	875.67a	864.83a	987.00a	1067.09a
2	CK_3	102.33g	192.33e	425.67b	335.37e	690.67c	599.67c	963.00a	1033.00a
3	GA_0	146.76f	155.36f	183.63g	191.38g	237.36g	246.32h	521.91f	429.91g
3	GA_1	218.21d	228.43d	232.30f	240.37fg	463.46d	472.08e	787.45c	695.55c
3	GA_2	202.00d	212.00d	245.67f	254.97f	315.67f	323.55g	528.67f	636.07d
3	GA_3	143.71d	151.02f	248.00f	258.00f	345.96e	353.06f	441.45g	559.95e
3	CK_0	125.33f	133.86fg	418.00b	398.00d	442.00d	452.93e	481.00f	491.77f
3	CK_1	157.33e	165.81f	333.67c	341.67e	363.00e	371.00f	662.67d	672.08d
3	CK_2	183.00e	193.00e	449.67b	457.09c	509.33c	519.33c	820.00b	830.66c
3	CK_3	109.00g	119.00g	353.00c	361.12e	481.33c	509.33c	703.33d	713.33c
p value		***0.042***	***0.049***	***0.034***	***0.047***	***0.041***	***0.045***	***0.010***	***0.038***
L.S.D		***19.74***	***21.76***	***21.61***	***56.93***	***37.80***	***26.50***	***45.82***	***49.63***

GA0-Control, GA1-0.225ml gibberellic acid, GA2-0.450 ml gibberellic acid, GA3-0.675 ml gibberellic acid, CK0-Control, CK1-0.225 ml cytokinin, CK2-0.50 ml cytokinin and CK3-0.750ml cytokinin. Values with the same letters in a column do not differ significantly at P<0.05

Table 2. The pods fresh weight (g) as influenced by the interaction between watering regimes and growth regulators

Irrigation schedule	Hormone treatments	Week 6		Week 7		Week 8		Week 9	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
1	GA_0	19.74d	24.74c	47.86b	52.87b	55.50c	59.45c	40.35d	46.35d
1	GA_1	32.40b	27.84b	49.58b	54.13b	61.19b	65.79b	51.65c	55.56c
1	GA_2	21.66d	25.66b	42.15c	47.55c	48.30d	52.38d	44.46d	48.23d
1	GA_3	14.79e	18.79f	30.10d	35.10d	39.51b	46.51e	41.10d	46.01d
1	CK_0	26.27c	30.27a	49.57b	53.57b	60.99b	64.99b	24.78a	28.78f
1	CK_1	27.67c	32.67a	60.30a	65.53a	72.78a	77.24a	31.99a	40.07e
1	CK_2	34.13a	35.83a	61.57a	65.57a	76.44a	80.84a	85.97a	84.99a
1	CK_3	32.93b	37.93a	47.13b	52.85b	58.78b	62.78b	20.77e	24.77f
2	GA_0	17.32b	21.32d	39.01c	34.51d	53.01d	47.01f	41.46d	36.86e
2	GA_1	26.52c	16.52g	42.87c	42.87c	58.17c	58.17d	44.68d	44.68d
2	GA_2	19.44d	14.44g	31.10d	35.61d	44.90f	48.09f	43.37d	43.37d
2	GA_3	11.31f	15.31g	31.01d	35.61d	41.10f	45.71f	42.51d	46.51d
2	CK_0	27.56c	31.56a	46.25b	50.87b	53.30d	57.93d	28.50a	28.50f
2	CK_1	26.72c	30.72a	55.54a	59.54a	61.29b	66.29b	60.55a	67.55b
2	CK_2	33.16a	38.86a	56.57a	61.87a	71.58a	74.58a	75.95a	85.95a
2	CK_3	28.93c	32.93a	42.38c	45.38c	50.70d	50.70e	42.09d	42.09d
3	GA_0	12.58f	18.58g	36.43cd	44.43c	42.70f	42.70f	47.17d	47.17d
3	GA_1	21.68d	34.68a	41.42c	46.42c	48.67e	52.94d	44.36d	44.36d
3	GA_2	18.41e	23.03e	39.75c	44.81c	41.74f	44.74e	41.33d	41.33d
3	GA_3	11.16f	15.16g	25.74e	29.54d	33.28g	38.31f	42.02d	42.02d
3	CK_0	22.99d	36.99a	39.25c	45.25c	46.57e	51.72e	38.70d	58.70c
3	CK_1	22.27d	28.87b	48.63b	53.82b	58.14b	58.14d	56.76b	56.76c
3	CK_2	26.20c	31.72a	48.67b	53.67b	55.40d	62.94b	54.40b	59.04c
3	CK_3	27.36c	31.36a	40.68c	44.08c	52.06d	57.86d	50.99b	50.99c
p value		***0.047***	***0.026***	***0.038***	***0.017***	***0.035***	***0.027***	***0.018***	***0.039***
L.S.D		***2.027***	***1.226***	***4.661***	***4.357***	***3.404***	***3.909***	***3.496***	***6.599***

GA0-Control, GA1-0.225 ml gibberellic acid, GA2-0.450 ml gibberellic acid, GA3-0.675 ml gibberellic acid, CK0-Control, CK1-0.225 ml cytokinin, CK2-0.50 ml cytokinin and CK3-0.750 ml cytokinin. Values with the same letters in a column do not differ significantly at P<0.05.

The increase on the leaf area of French beans under the growth regulators agree with findings of [12] who reported that application of gibberellic acid at vegetative stage increased biomass and provided greater area for photosynthesis. Moisture scarcity limits crops growth and leaf area thereby adversely affecting photosynthesis and productivity. Application of growth regulators alleviated water stress of the crops, hence improving photosynthesis and thus the leaf area. However use of gibberellic acid at 0.675ml revealed lower leaf area than the control, meaning that high concentrations of the hormone is injurious to French beans.

The phytohormones have been known to be associated with leaf development in several plants species. When they are exogenously applied they lead to more leaf growth [11]. The gibberellic acid induced leaf growth and development in the French beans with increasing gibberellic acid up to a threshold concentration. Author [13] found that foliar application of indole-3-butyric acid with different concentrations led to significant increases in vegetative growth, plant height, number of leaves per plant, fresh and dry weight per plant, leaf area per plant and concluded that the possible solution to reduce the effects of water stress on plants is the application of exogenous growth regulators, especially those that delay leaf senescence (cytokinins), to prevent the abortion of fruits (auxins and gibberellins) and increase the area leaf (gibberellins).

3.3 Fresh Pod Weight per Plant

Significant differences at P<0.05 were revealed between the interaction of growth regulators and watering regimes on the harvested fresh weights of pods in all the four weeks of harvesting. The highest fresh pod weight per plant was observed during the final harvest at week nine with 85.97 g/plant and 84.99 g/plant in the first and second seasons respectively (Table 2). The rate of 0.50 ml of cytokinin at one and two day watering intervals showed the highest fresh pod yield during the first season of week six and the same rate and the two day watering interval had the highest pod yield during the second season of the same week. During week seven, the 0.250 ml and 0.50 ml of cytokinin and a daily watering regime had the highest pod yield for both seasons which was however insignificantly different from the two day watering interval which had a marginally lower pod yield under the same hormone in the same levels. The last two weeks of harvesting showed 10%-20% increase on the fresh pod yield per plant where the 0.50 ml rate of cytokinin in both the one and two-day watering intervals had the highest fresh pod yield per plant although at one day watering interval the harvest was slightly higher but insignificantly different from the two days watering interval. The highest level of gibberellic acid led to the least yield of pods as well as the lack of either of the growth regulators as shown on Table 2. The plant growth regulators have been reported to have a threshold limited action that at certain concentrations levels may become toxic to the plants. This study demonstrated that French beans are sensitive to water stress and water deficits where use of regulators showed to be a promising remedy and confides with earlier findings by [14]. Moisture stress has been found to be one of the major factors in limiting French beans productivity in the world [15,16] and found that one of the solutions to reduce effects of moisture stress to French beans is by the application of growth regulators that delay senescence (cytokinin) and that prevent fruit abortion and increase leaf area (gibberellic acid). Low levels of moistures modified the allocation of resources thereby decreasing translocation of resources to the pods. Application of plant growth regulators at the vegetative and flowering stage increased plant biomass and fruiting. This further provided source for allocation of resources for the formation of pods [12].

Cytokinin are regarded as the most important senescence retarding hormones and their exogenous application has been demonstrated to prevent degradation of chlorophyll and photosynthesis of proteins as well as reversing leaf and fruit abscission. Cytokinin stimulates leaf expansion, development of reproductive organs and delays senescence [17]. The gibberellic acid promoted cell elongation, the cambium activity and stimulates protein synthesis. However, high concentration of gibberellic acid inhibits plant growth. This observation agrees with findings by [18] who found out that gibberellic acid is the most important growth stimulating plant growth regulator that is used for the cell elongation and thus promotes plant growth and development in legumes. Author [19] found that foliar application of gibberellic acid in legumes overcame adverse effects of salts hence improvement of water uptake. When exogenously applied these growth regulators lead to petal growth and flowering induction in both long day and short day plants. Black cardinal plants were induced to flowering under non inductive conditions through application of gibberellic acid, increasing flowering and inflorescence number per plant with increasing gibberellic acid concentrations up to threshold level [12]. Several plant species are induced to flowering by phytohormones after water scarcity or low moisture availability [20]. Improved water availability and the phytohormones (up to threshold limit) enhanced flowering. Conversely, lower water availability and phytohormones (beyond threshold level) negatively affected French bean flowering and inflorescence development which is a precursor for pod formation and yield.

4. CONCLUSION

The French beans farming requires regular water supply, especially around flowering and grain filling. Daily and two-day water application and 0.50 ml rate of cytokinin resulted in the highest French beans yield in all the harvestings. This therefore shows that in places where there is plenty of water for irrigation the application at a one-day interval is recommended and if there is partial availability a two-day interval will as well manifest significantly the highest yields of the crop but in highly limited water conditions, the hormone at the same rate will lead to the highest yield thus recommended.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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