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Effect of Sowing Dates, Irrigation Levels and Climate Change on Yield of Common Bean (*Phaseolus vulgaris* L.)

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Abstract: Climate change and population growth are the two most important challenges faced by agriculture today. This study was conducted in a netted greenhouse in order to investigate the effect of climate change on common dry bean yield (*Phaseolus vulgaris* L. cv. Nebraska). A field experiment was conducted at the Experimental Farm of Environmental Studies and Research Institute-Minufiya University- Sadat Branch in the two successive winter seasons of 2006/07 and 2007/08. The experiment included three sowing dates (September 5th, September 19th and October 3rd) as well as two irrigation levels (50% and 100% of potential evapotranspiration) arranged in a split-plot design with three replicates. The results indicated that the first sowing date gave the highest vegetative and yield values. The 100% irrigation gave higher vegetative and yield parameters than 50% irrigation. The results were used to validate The Decision Support System for Agrotechnology Transfer, (DSSAT model) under the Egyptian conditions. The validated model was used to investigate the potential impact of climate change (+1.9 and 2.5 °C) on common dry bean yield for the years 2025 to 2100. Seed yield (without adaptation) is projected to be reduced by 8 to 22% for the years 2025 to 2100. Seed yield could be reduced from 4.36 to 16.26% (with adaptation) is estimated for the years 2025 to 2100 when sowing date was delayed from 5th of September to 5th of October. Moreover, it is recommended to develop a new drought and heat-tolerant varieties of dry common bean in Egypt.

Key words: DSSAT model · Yield projection · Decision support

INTRODUCTION

According to Food and Agriculture Organization Statistics [1], common bean (*Phaseolus vulgaris* L.) is globally grown in nearly 28 million ha and produced about 20 million ton. Its average yield in the world ranged from 493 kg in 1961 to 729 kg/ha in 2008. Although average yield of common bean has been gradually increased starting from 1999, it has been recorded as irregular after the new millennium [1]. The average yield is low and unstable due to abiotic stresses [2], while common bean has high yield potential as 5 tonnes/ha [3]. One of the reasons of these fluctuations in average yield is climate change. Intergovernmental Panel on Clime Change (IPCC) reported that global surface temperature has increased 0.74 ± 0.18°C from 1905 to 2005 (during 20th century) due to the environmental greenhouse effects [4]. Climate model projected that surface temperature is likely to rise between 1.4 and 5.8 °C during 21st century [5]. Thus, the impact of this type of climate change will probably lead to a decline in crop productivity [6]. Light and temperature are the most important environmental factors that affect plant growth, development and biological yield [7]. Consequently, sowing date is one of the most important factors which have a paramount effect on dry common bean development, growth and biological yield [8, 9]. According to Free [10], common bean requires moderate amounts of water (300-600 mm per season). Adequate amounts early in the season are essential, particularly during the pod-filling stage (during and immediately after flowering) where the soil should not hold more than 60% of field capacity to insure proper moisture availability. Low irrigation level reduced total leaf area/plant and number of leaves [11] and induced reduction in crop growth [12]. Singh [13] found that vegetative growth increased linearly with irrigation amounts from 0 to 100%.

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Moreover, El-Noemani *et al.* [14] in Egypt, irrigated bean plants by 100%, 80% and 60% of Et_0. They revealed that increasing irrigation treatment up to 100% Et_0 exhibited the highest values of vegetative growth. However, the highest values of pods yield/fed were achieved by 80% Et_0 treatment.

This study was carried out to investigate the effects of sowing dates, irrigation levels and climate change factors under future conditions on growth and productivity of common beans in Egypt.

MATERIALS AND METHODS

The present work was conducted under a netted greenhouse conditions at the Experimental Farm of Environmental Studies and Research Institute, Minufiya University, Sadat Branch, during the two successive seasons of 2006/07 and 2007/08. Data were used for the validation of the DSSAT model. The greenhouse was covered by a commercial anti-insect screen net (Alserran). The experiment aimed to study the impact of climate change on growth and biological production of dry common bean. Just before planting, representative composite soil samples of three depths (0-30 cm) were collected, air dried, pulverized, passed through a 2 mm sieve and thoroughly analyzed for some selected physico-chemical characteristics according to the method described by Klute and Dirksen [15] as shown in Table 1. Field capacity (F.C.) and permanent wilting point (P.W.P.) were determined according to Black [16] and are shown in Table 2.

Experimental Design and Treatments: The experiment was designed in a split-plot with three replicates. The two irrigation treatments (50% and 100% of potential evapotranspiration) were assigned in the main plots. Evapotranspiration was estimated using agroclimatic data retrieved from the automatic weather station in the site. Three sowing dates were adopted: 5th September, 19th September and 3rd October in both seasons of 2006/07 and 2007/08 and were arranged in the subplots. The area of the experimental unit was consisted of 2 rows 3.0 m long and 1.4 m width, with three replicates for each treatment.

Field Preparation and Agricultural Practices: The recommended amount of seeds (40 kg/ fed. of dry bean seeds) of Nebraska cultivar, were bought from the Horticulture Research Institute, Agricultural Research

Table 1: Physical and chemical properties of the experimental soils (average of the two seasons).

Mechanical analysis									
Sand%	Silt%	Clay%	Texture	pH	EC dS/m	Saturation%	Carbon exchange capacity mole/kg	Total organic carbon%	O.M. g/kg
14.04	76.41	9.55	Silt - loam	7.3	2.0	18.9	20.2	0.5	7.8

Chemical analysis									
Cations (meq/L)				Anions (meq/L)			Available macronutrient mg/kg		
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	CL^-	SO_4^{--}	N	P	K
8.3	3.4	6.9	1.4	1.9	3.5	14.6	42.0	7.2	103.0

Table 2: Field capacity, wilting point and bulk density of the soil in the experimental site (Average of the two seasons).

Soil depth (cm)	Moisture content at field capacity (%)	Wilting point (%)	Soil bulk density (g/cm^3)
0 - 30	19.2	10.02	1.45
30 - 60	19.0	9.5	1.50
Average	19.11	9.78	1.48

Table 3: Irrigation period, number of irrigations/ season, irrigation water/day and irrigation water/ season as affected by irrigation treatments during the two growth seasons (under shaded house).

Treatments	Variable							
	Irrigation period, days		No. of irrigations/ season		Irrigation water m^3/ fed*. /day		Irrigation water m^3/ fed. /season	
Evapotranspiration (Et_0)	S1	S2	S1	S2	S1	S2	S1	S2
100 %	110	110	90	90	18.5	17.6	1663	1580
50 %	110	110	90	90	9.2	8.8	832	790

S1 = 2006/07 season, S2 = 2007/08 season.

* fed. = One feddan = 4200 m^2

Table 4: Average climate data (A1 scenario) of dry bean winter season (Sep. Oct. Nov. Dec. and Jan.).

	2007/08		2025		2050		2075		2100	
Location	Max.Temp.	Min.Temp.	Max.Temp.	Min. Temp.	Max. Temp.	Min. Temp.	Max. Temp.	Min. Temp.	Max. Temp.	Min. Temp.
Sadat	24.0	14.0	24.4	13.0	25.3	13.9	25.9	14.5	26.2	14.8

Center, Giza, Egypt and were sown to achieve the needed plant density. Irrigation period, No. of irrigations/season, irrigation water/day and irrigation water/season for the two irrigation treatments during the two growth seasons are shown in Table 3. All other agricultural practices were followed as local recommended instructions. Plants were irrigated daily using drippers of 2 L/h discharge.

Crop Simulation: Field data were used by CROPGRO-dry bean model [17] in order to simulate and predict dry common bean growth development and yield. The model was adapted by Boote *et al.* [18] in order to validate dry bean growth and yield. The experimental data were prepared on the basis of IBSNAT [19]. The climatic data of the location included four daily weather parameters, i.e. temperature (maximum and minimum), total solar radiation, humidity (maximum and minimum) and rainfall.

Crop Data: Random samples of three plants were taken from each experimental plot to assess the vegetative growth parameters. The data recorded or estimated were: plant fresh and dry weights (g) every week during the growing season; flowering date (number of days from sowing to 50% flowering of population); dry weight of seeds (g m^{-2}); dry weight of pods (g m^{-2}); average dry weight of 100 seeds (g); average number of seeds per pod; number of pods and number of seeds per m^2 (recorded or estimated after harvest).

Climate Change Data: The projected climatic data under climate change conditions for the time series 2025s, 2050s, 2075s and 2100s of the experimental location were obtained and estimated for maximum and minimum air temperature (Table 4). Temperature variations were obtained for both A1 (worst case) scenario of the IPCC using MAGICC v.4.1/SCENGEN, which is the climate model that has been used in all IPCC assessments to produce projections of global-mean temperature. The A1 scenario describes a future world of a very rapid economic growth, global population that peaks in mid-century and efficient technologies [20].

Statistical Analysis: The obtained results were subjected to analysis of variance according to the procedure outlined by Snedecor and Cochran [21] and significant differences were weighed by LSD test at 0.05 level of probability.

RESULTS

Yield and Yield Components of Common Bean: Irrigation level of 100% was superior compared to its counterpart 50% rate in terms of fresh and dry weight of plant (Tables 5 and 6). It was obvious that sowing dates of September 5^{th} and 19^{th} were almost the same at 50% irrigation level for the first season, regarding the dry weight. On the other hand, sowing date of September 5th was the most proper sowing date giving the highest fresh and dry plant weight. Dry weight of plant (g/plant) was influenced significantly by the interaction between irrigation levels and sowing dates; however no significant differences could be found to the interaction between sowing dates and irrigation levels for the second season (Table 6).

Data presented in Tables 5 and 6 indicated that pods yield/m^2 did not vary significantly in the two seasons due to the sowing dates, on contrary to irrigation level. In other words, irrigation level at 100% led to a significant increment in pods yield. However, sowing date of September 5^{th} and irrigation level of 100 % resulted in the highest pods yield. Such a trend was also true for seeds yield/m^2. On the other hand, the highest yield of pods and seeds (g/m^2) was achieved in the first sowing date (September 5^{th}) in both seasons. D ata also in Tables 5 and 6 revealed that weight of 100 seeds was significantly influenced by sowing date during the first season (2006/07). On contrary to the second season (2007/08) in which significant differences could be traced in this respect. It is worthy to mention that there was noticeable increment in 100 seeds weight for 100% irrigation levels as compared to 50% rate, in both seasons investigated in the present study. The first sowing date (September 5^{th}) with either 50% or 100% irrigation level exhibited the highest weight of 100 seeds.

Number of pods/m^2 exhibited the highest value by applying 100% irrigation level at the first sowing date. As sowing date was delayed, the number of pods/m^2 decreased. The same trend was noted at 50% irrigation but with less number of pods/m^2 than their counterparts

Table 5: Effect of irrigation levels and sowing dates on yield biomass of dry bean plants for 2006/07 season.

Sowing date	Plant weight (g plant^{-1}) Fresh wt.	Dry wt.	Yield (g/m^{-2})[1] Pods	Seeds	Wt. of 100 seeds (g)	Number of pods (m^{-2})	Number of seeds (m^{-2})	Days to flowering
				50 % irrigation				
5 Sep.	51.4	33.1	171.0	119.7	47.7	92.3	211.3	37
19 Sep.	38.3	33.1	185.5	125.9	41.3	85.0	251.0	33
3 Oct.	27.1	23.0	143.3	99.4	43.0	88.0	378.3	30
Mean	39.1	29.7	166.6	115	44	88.5	280.5	33.3
				100 % irrigation				
5 Sep.	58.2	42.8	260.2	183.5	55.1[a]	130.7	349.3	42
19 Sep.	55.6	45.2	210.6	171.4	49.5[a]	121.6	362.2	35
3 Oct.	52.9	45.0	179. 3	130.1	52.5[a]	99.1	272.3	31
Mean	55.6	44.3	163.4	161.7	52.4	117.1	327.9	36
				Means of sowing dates				
5 Sep.	54.8	37.95	215.6	151.6	51.4	1115	280.1	40
19 Sep.	46.95	39.19	198.1	148.7	45.4	103.3	307.1	34
3 Oct.	40.2	34.1	107.5	114.7	47.7	93.65	325.3	31
F-test I	ns	Ns	*	*	Ns	*	Ns	ns
S	ns	Ns	Ns	ns	*	ns	Ns	ns
I x S	ns	*	Ns	ns	Ns	ns	Ns	ns

Means followed by a common letter in the same column are not significantly different at the 5% level by DMRT.

[1] mean of 9 plants

Table 6: Effect of irrigation levels and sowing dates on yield biomass of dry bean plants for 2007/08 season.

Sowing date	Plant weight (g plant^{-1}) Fresh wt.	Dry wt.	Yield (g/m^{-2})[1] Pods	Seeds	Wt. of 100 seeds (g)	Number of pods (m^{-2})	Number of seeds (m^{-2})	Days to flowering
				50 % irrigation				
5 Sep.	49.4	37.2	181.0	120.7	47.8	95.7	219.3	35
19 Sep.	38.3	33.1	185.5	123.9	40.3	95.0	281.0	30
3 Oct.	27.1	23.0	143.7	96.5	43.0	88.0	188.3	28
Mean	38.3	31.1	170.1	113.7	43.7	92.9	229.5	31
				100 % irrigation				
5 Sep.	57.4	43.8	259.2	183.9	50.1	128.7	359.3	40
19 Sep.	53.6	47.5	201.7	168.4	48.3	122.7	366.3	33
3 Oct.	50.9	45.0	183.3	129.9	51.0	97.7	271.3	29
Mean	54.0	45.4	214.7	160.7	49.8	116.4	332.3	34
				Means of sowing dates				
5 Sep.	53.4	40.5	220.1	152.3	49.0	112.2	289.3	38
19 Sep.	46.0	40.3	193.6	146.2	44.3	108.9	323.7	32
3 Oct.	39.0	34.0	163.5	113.2	47.0	92.9	229.8	29
F-test I	Ns	Ns	*	*	Ns	*	Ns	Ns
S	Ns	Ns	Ns	ns	Ns	ns	Ns	Ns
I x S	Ns	Ns	Ns	ns	Ns	ns	Ns	Ns

Means followed by a common letter in the same column are not significantly different at the 5% level by DMRT

[1] mean of 9 plants

Table 7: Effect of irrigation levels and sowing dates on actual and estimated dry yield of dry common bean under futuristic climate change conditions, year 2100, with and without adaptation as compared to predicted yield.

		Biological dry yield									
		Pods					Seeds				
Sowing date	Irrigation levels	Predicted 2007/08 (Kg/ ha)	Without adaptation 2100 (Kg/ ha)	Δ, % of Predicted 2007/08	With adaptation* 2100 (Kg/ ha)	Δ, % of Predicted 2007/2008	Predicted 2007/08 (Kg/ ha)	Without adaptation 2100 (Kg/ ha)	Δ, % of Predicted 2007/08	With adaptation 2100 (Kg/ ha)	Δ, % of Predicted 2007/2008
5 Sep.	50%	1821	1364	-25.11	1472	-19.11	1213	944	-22.16	1016	-16.26
	100%	2973	2315	-22.14	2493	-16.14	1850	1477	-20.16	1586	-14.26
19 Sep.	50%	1864	1411	-24.32	1522	-18.32	1245	981	-21.23	1054	-15.33
	100%	2033	1602	-21.20	1723	-15.26	1692	1349	-20.31	1451	-14.29
3 Oct.	50%	1444	1110	-23.15	1196	-17.15	969	764	-21.11	822	-15.19
	100%	1842	1469	-20.23	1580	-14.23	1307	1055	-19.23	1132	-13.36

* Change in planting date +30 days from normal date.

100% irrigation level. This was true for both seasons (Tables 5 and 6). Number of seeds/m^2 showed the highest value at 100% irrigation level at the second sowing date (September 19th) in both seasons. As for 50% irrigation level, the highest number of seeds/m^2 was achieved at the third sowing date (October 3rd) in the first season, on contrary to the second season in which the second sowing date at 50% irrigation level gave the highest number of seeds/m^2 (Tables 5 and 6). Days to flowering increased at 100% irrigation level as compared to 50% irrigation level. As for interaction between sowing dates and irrigation levels, the irrigation level of 100% at the first sowing date (September 5th) resulted in elongation the days to flowering. Delay of sowing date obviously shortened the days to flowering for 50% and100% irrigation level with shorter period for the former as compared to the latter.

Crop Model Validation for Current Climate: Data presented in Table 7 illustrated that the comparison between field data and predicted data obtained by the DSSAT [22] software, for pods and seeds dry yield (kg/ha) of common beans at the three sowing dated and two irrigation levels. Data of the validation experiment indicated that the CROPERP- legume model can be applied successfully to predict the yield under Egyptian conditions. Data revealed that sowing date of September 5, along with 100% irrigation level resulted in increment of pods and seeds dry yield.

Effect of Irrigation Levels and Sowing Date on Simulated and Predicted Dry Common Bean Yield: It was clear that delay sowing date from September 5th to October 3rd resulted in a graduate decline in yield of pods and seeds yield of dry common bean. Accordingly, dry bean crop has to be planted on September 5th to maximize the crop yield. Meanwhile, 100% irrigation level was found to increase the yield of dry common bean as compared to 50% irrigation level (Table 7).

Effect of Irrigation Levels and Sowing Dates in Common Bean Production under Futuristic Climate Change Conditions: The potential impact of climate change on pods and seeds yield of dry common bean were evaluated by simulating different sowing dates and irrigations levels, to predict the yield as effected with climate change scenario (A1) by the years 2025, 2050, 2075 and 2100 as compared with that predicted under the current conditions of 2007/08 season (Table 7).

Options to Reduce the Negative Impacts on Biological Dry Common Bean Production: Data presented in Table 7 indicated that under climate change scenario (A1) decreased dry common bean production, when different sowing dates were applied by the years 2100, as compared with the crop yield in 2007/08 season. To eliminate such a negative impact of climate change sowing date can be changed from September 5th to October 5th. It is worth to notice that sowing date of November 3rd reduced the decline of production from (-11.5 to -25.0 % to 3.0- to 14.0 %) for pods and from (-8.0 to -22.5 % to -4.0 to - 13.0%) for seeds.

DISCUSSION

As water for irrigation purpose becomes increasingly scarce because of climate change and population growth, there is growing interest in regulated deficit irrigation as a way to improve efficiency of water usage and farm productivity in arid and semi-arid areas [23]. On the other hand, according to IPCC[4], continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those the 20th century. The problem of global warming is becoming a fact that should be taken seriously into consideration. According to a report by the Intergovernmental Panel on Climate Change (IPCC), surface temperature enhanced 0.74±0.18 °C between the start and the end of the 20th century [4]. The relative stability in temperature from 2002 to 2009 is consistent with such episode [24] and Global temperature slowdown-not an end to climate change [25]. There are some evidences of regional climate change affecting system related to human activities, including agricultural and forest management activities at higher latitudes in Northern Hemisphere [4]. Future change is expected to particularly affect some sectors and systems related to human activities [5]. These include: water resources in some dry regions at mid - latitudes, the dry tropics and areas that depend on snow and ice melt, agriculture in low latitudes; low lying coastal systems and human health in populations with limited capacity to adapt to climate change.

The Decision Support System for Agro-Technology Transfer (DSSAT model) was used and validated, in the present study, in order to simulate the Egyptian conditions and thereby was utilized to investigate the potential impact of climate change on dry common bean production, for the year's 2025 to 2100. Sowing date of September 5 and irrigation level of 100% were superior in terms of pods yield. These data are in accordance with data published by Begum *et al.* [26].

The point of interest is that irrigation level led to a significant increment in pods number at 100% irrigation level on contrary to number of seeds. Sowing date affected significantly number of seeds/pod at irrigation level of 100%. Moreover, El-Noemani *et al.* [14] in Egypt, irrigated bean plants by 100%, 80% and 60% of Et_0. They revealed that the highest values of green pods yield/fed were achieved by 80% Et_0 treatment. On the other hand sowing date did not affect significantly the number of seeds/pod at 50% irrigation level (Table 5). Our data are in agreement with those obtained by Bourgault *et al.* [27] who found that yields of common bean decreased with increasing soil water depletion levels. It is worth to mention that there are several indications that mungbean responded to water stress through dehydration avoidance rather than dehydration tolerance [23]. Consequently, it can be concluded that the early sowing date increased number of pods/m^2. These results are in a good agreement with those reported by Reilly [25] and Long *et al.* [28]. The difference percentage between observed and predicted data varied from 0.4 to 0.8%. Similar results are in agreement with the findings of El-Marsafawy *et al.* [29]. It was clear that the predicted increment in temperature will result in a decline in crop production between 1.2 and 1.8°C in the period (2010-2039). This increase is higher than the predicted temperature change in dry bean production area which was found to be between 0.9 and 1.7°C for the period (2010- 2039) and between 1.6 and 3.0°C for the period (2040 - 2069).

In a conclusion, common bean adapted would do little to counter balance the negative temperature effects resulted in the simulation. Current Egyptian common bean production is limited to cultivar that requires a period of cold weather for seeds initiation. The only viable strategy to reduce yield decline would be a change in the sowing date to allow the storage of carbohydrates and to give enough time for leaf area development period to seeds initiation.

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