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Original Paper

Effects of Regulated Deficit Irrigation on Yield and Yield Components of Capsoly Bean

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***Abstract*— Common bean (*Phaseolus vulgaris L.*) is a key protein source but is limited by water stress. Water scarcity, worsened by climate change, particularly affects arid regions like Afghanistan. A two-year field experiment at Kabul University tested five irrigation treatments: full irrigation (CFI), deficit at vegetative (VD), flowering (FD), pod formation (PD), and grain-filling (GD) stages. Deficit irrigation during flowering and pod formation significantly reduced pod number, pod length, grains per pod, 100-grain weight, and yield, while deficits at vegetative and grain-filling stages had minimal effects. These findings indicate that common bean tolerates water stress during vegetative and grain-filling periods, but is sensitive during flowering and pod formation, highlighting the importance of irrigation timing for maximizing yield.**

Keywords*— Bean growth stages, Deficit irrigation, Drought, Water, Water stress.

I. INTRODUCTION

Common bean (*Phaseolus vulgaris L.*) is an important grain legume. Grain legumes are a rich source of protein (16–50%), dietary fiber (10–23%), essential elements (Fe, Ca, Mg, Zn, and K), and vitamins (Gargi et al., 2022). They are precious gifts to mankind and are often known as the poor man's meat. Grain legumes are a storehouse of multiple nutritional components that include carbohydrates, sugars, vitamins, mono- and polyunsaturated fatty acids, as well as more than 15 essential mineral elements. Grain legumes also contain folic acids, lectins, phytate, trypsin inhibitors, and polyphenolic non-nutritional bioactive components. Pulse (grain legume) inclusion in a diet plan prevents a person from various health problems (e.g., type 2 diabetes, cardiovascular diseases, and some forms of cancer), and it also reduces the risks of obesity (Admasu et al., 2019).

Common beans have a rich nutritive composition among legume grains and are mostly considered a complete food around the world; their versatile property in cooking and processing makes them a valuable and most consumed crop in the world. In developing countries, the common bean is an essential component of the human diet (Maleki et al., 2017). This legume grain is the cheapest source of protein and has a dense amount of protein content, supplies energy, a wide amount of fiber, and complex carbohydrates (Rathna and Manickavasagan 2020). Beans are a non-meat source of iron and can provide 23-30 % of the daily recommended levels (Manjeru, 2007). This legume contains other nutritious components, including a wide number of antioxidants, minerals, and bioactive compounds (Abdel-Baset, Sahar H, 2022). The globally common bean has grown in 34.80 million hectares, and its production has risen to 27.54 million tons per year (FAOSTAT, 2022). It is a diet of over 300 million people as a nourishing food globally. Since it was discovered that the common bean is associated with rhizobium and can fix the atmospheric nitrogen in the soil, it plays a significant role in crop rotation and sustainable cropping systems (Simsek, 2011). Nitrogen fixation improves the soil nitrogen level, which is beneficial for the following crops and reduces the production cost. Its residues increase soil fertility and improve the soil structure (Manjeru, 2007).

The main effect of domestication in crops is a reduction in the crop's genetic diversity relative to their wild progenitors. This arises from the reduction in population size, which causes a constriction in diversity at the genome-wide level, and from selection at target genomic regions (Freytag and Debouck, 2002). In this context, the common bean (*Phaseolus vulgaris*) is characterized by a particular evolutionary history. Phaseolus species are of particular interest because of the multiple domestications that have taken place in this genus. Indeed, of the 70–80 wild species that have been described, no less than five species have been domesticated in contrasting ecogeographic settings: common bean (*P. vulgaris L.*); lima bean (*P. lunatus L.*); runner bean (*P. coccineus L.*); tepary bean (*P. acutifolius A. Gray*); and year bean (*P. dumosus Macfady*) (Cortés et al., 2018). In addition, the first two species were independently domesticated at least twice in Mesoamerica and the Andes, implying that some domestication traits may have been selected multiple times, as shown by the determinacy trait in common bean (Blair et al., 2012).

Mesoamerica is the main region of origin, where the maximum number of Phaseolus species are geographically distributed, and it is assumed that the Phaseolus genus originated between 4 and 6 million years ago in this region (Blair et al., 2012). Having originated in Mesoamerica, what is now Mexico, wild forms of common bean were mainly distributed from northwestern Argentina to northern Mexico, resulting in the formation of unique gene pools. Some research reported that Mesoamerica was the first place where the common bean was domesticated (Rao et al., 2017). Despite the uncertainty regarding the geographic origin of *P. vulgaris*, several lines of evidence from traditional (allozymes or seed proteins) and more recent molecular markers converge in the establishment of two geographically and genetically isolated gene pools, one in Mesoamerica and one in the central to southern Andes. From these pools, two independent domestications took place starting about 8000 years ago, followed by local adaptations and further expansions (Kamfwa et al., 2015). Multiple species of common beans, such as red bean, white bean, black bean, pied bean, and motley bean, are cultivated and spread out in different parts of Afghanistan according to its climatic conditions (Blair et al., 2012). While overall agriculture and connected livelihoods in Afghanistan suffer from an arid to semi-arid climate with very little rainfall in the summer growing season, drought in the past few decades has worsened these conditions, particularly in high-elevation regions.

Legumes, or pulses, are flowering plants in the *Fabaceae* (*Leguminosae*) family. The word legume is derived from the Latin verb Legere, which means to gather. The term pulse has a more direct lineage (Diaz et al., 2020). It derives from pull or porridge, a bean-cooked dish that the ancient Romans were fond of eating. This family is also known as Fabaceae, and both terms can be used interchangeably to indicate some 690 genera and 18,000 species therein (Pereira et al., 2020). The Leguminosae family is classified into three sub-families: *Papilionoidea*, *Caesalpinioideae*, and *Mimosoideae*. Its flowers identify with each sub-family. Edible legume crops are mainly found in the sub-family Papilionoidea. This includes soybean, chickpea, bean, and pea, among others. The most prominently cultivated of these are the genera Phaseolus, Vigna, Vicia, and Glycine. Within the genus, Phaseolus is the species tepary bean (Latin name *acutifolius*), runner bean (coccineus), lima bean (*lunatus*), and common or pinto bean (*Vulgaris*). The word Phaseolus comes from the Greek phaselus, "which refers to a canoe-like boat reminiscent of a bean pod". Common beans are an annual herbaceous plant with great diversity in its growth habit; for instance, it may be a determinate/indeterminate bush or a climber to semi-climber vine.

Climate change poses a significant threat to worldwide crop productivity as it impacts crop growth, flowering, and yield. Consequently, any alteration in climate that results in elevated temperatures and altered rainfall patterns due to heightened greenhouse gas concentrations in the atmosphere will have a significant impact on agricultural output (Ntukamazina et al., 2017). Global warming and climate change due to anthropogenic activities add carbon compounds such as carbon dioxide, methane, carbon monoxide, etc., into the atmosphere, which deteriorates soil health and reduces the production potential of the region even under irrigated conditions. Meanwhile, climate change is not the only environmental factor that limits global crop production; drought and some other factors, such as salinity, soil compaction, pollution, and flooding, limit crop production as well. These are the elements that decrease the quality and quantity of all crop yields (Karavidas, 2022). Over the past decades, climate variability has become one of the main concerns of scientific communities. Agriculture in the future will face multiple challenges that include the production of more food and fiber for billions of people and higher production of feedstock for bioenergy production (Ahmad, 2023).

One of the most common and important impacts of climate change is changing the rainfall patterns (quality, quantity, and distribution) across the world, and in some regions, drought will be more frequent and severe (Victore, 2009). This tells us that we need much more water in the future. It is estimated that 60% of common bean production occurs under the risk of intermittent or terminal drought stress. These conditions cause yield losses of between 10% and 100%. Substantial research efforts have been made to improve the resilience of common beans to drought. Climate change is negatively affecting the agriculture sector in many developing countries (IPCC 2009). Crop productivity in developing countries is expected to decline under future climate (Jones and Thornton, 2009). Like many other crop species, climate change is expected to have adverse effects on common change. For example, common beans are grown at mean air temperatures of 14–35 °C, whereas day temperatures or night temperatures above 30 or 20 °C, respectively, result in significant yield reduction (Beebe et al., 2011)

According to the NSIA report, pulse crops were cultivated in 111,894 ha of farmland in 2016 (NSIA, 2016-17). It is also worth mentioning that domestic arable lands occupy approximately. 12% of the total country's area, including about 5% irrigated land and about 7% rainfed (Ayubi, 2019). However, the traditional irrigation systems have very low efficiency, leading to considerable water losses during irrigation sessions.

II. MATERIALS AND METHODS

A. *Description of the Experiment Site*

The field trial was conducted for two continuous years at the Experimental Farm of the Agriculture Faculty, Kabul University, Kabul, Afghanistan, from June to September of 2021 and 2022. Geographically, the research farm is located between 34° 31' 03.3" North latitude and between 69° 08' 21.6" East longitude. The altitude is about 1791 m above sea level. This area falls under a semi-arid climatic zone.

Field preparation

Field preparation started on 28/ 5/ 2021 for the first trial, and the second year started on 1/6/2022. Simple hand tools were used for working the land, constructing the furrows, and shaping and leveling the experimental plot, and a tractor was used for plowing the land.

Planting

The field was entirely tiled using a tractor plow to make the surface effective for unrestricted penetration of the roots to the ground and air exchange interface for better root distribution in the ground. Bean grain was planted on June 2, 2021, three days after land preparation. Each plot contained six lines that lay in a horizontal shape. Plant-to-plant space was 20 cm, and row-to-row spacing was 40 cm in every individual plot. For optimum seed germination and seedling establishment, bean seeds were immersed in water for 15 hours to absorb enough water before sowing.

Maintenance practices

Crop maintenance practices were done by controlling the weeds' development using simple weeding tools; the weeding practice was performed every 15 days. This strategy minimized weed competition with the main crop. Another practice was scouting for disease symptoms and caring about pest invasion through scouting the population of pests in the field area, and finally, the amount of water was depleted regularly as scheduled.

Soil properties

Soil medium is an essential element for plant growth, biotic and abiotic activities, and geophysical properties of soil substantially affect the plant growth, development, and finally the economic return of the yield. By using an auger before experimentation, the samples were collected randomly at a depth of 0-25 cm. The prescribed technical precautions, which are necessary for standard sampling, were considered. Then the samples were brought to the laboratory, dried at room air temperature, and thereafter passed through a 2mm sieve.

The obtained samples were subjected to various analyses, such as chemical, physical, and mechanical, to assess the soil's physical and chemical properties. The soil of the experimental plot was clay loam with a slightly alkaline reaction; the soil nutrients, such as N, P, and K levels, were lower than the plant needs.

Meteorological conditions

The research farm is in a region with semi-arid climatic conditions and about 300 mm of annual rainfall, which varies in the period. The annual mean maximum air temperature was recorded as 22.28°C with a range of 11.5 to 35.1 °C, and the mean minimum air temperature was recorded as 6.6°C with a range of -4.3 to 19.3°C (Meteorological department, 2021,2022). The mean annual relative humidity was about 52%, and vice versa, the potential pan evaporation was recorded at 1495 mm in 2021 and 1650 mm in 2022.

Experimental details

The study was conducted in a randomized complete block design (RCBD) with five treatments and three replications. The irrigation regimes were designed based on growth stages such as (T1: V100 -F100 -P100 -G100,) which all growth phases were irrigated fully (T 2: V50 -F100 -P100 -G100) in this treatment vegetative growth of bean crop was encountered to water deficit, (T3: V100 -F50 -P100 -G100,) flowering period of bean crop was encountered to water deficit, (T4: V100 -F100 -P50 -G100) pod formation period was encountered to water deficit and finally (T5: V100 -F100 -P100 -G50) treatment grain filling period of bean crop was encountered to water deficit. Treatments were basin irrigated with a 2.5 m length and 2 m width, and the trials were irrigated using a siphon. The bean crop was cultivated at 40 and 20 cm spaces between rows and plants, respectively. The irrigation setup was determined using Cropwat software (FAO Cropwat 8.0).

TABLE I. EXPERIMENTAL SETUP

B. Irrigation Set up

Block Treatment	I	II	III
I	C_{FI}	G_D	V_D
II	F_D	V_D	C_{FI}
III	P_D	P_D	F_D
IV	V_D	F_D	G_D
V	G_D	C_{FI}	P_D

Irrigation setup determines the correct measure of water to irrigate and the correct time for watering. The CROPWAT model calculates the ET0, CWR, and IRS to develop irrigation schedules under drought conditions. For providing moisture in regions with insufficient precipitation to the soil, which is deficient and cannot supply the required moisture needed for growing crops, irrigation was generally considered as a supplemental water application to the field. This phenomenon is a practice of supplementing the natural moisture that is provided by precipitation to increase the crop yield. The surface irrigation system has the lowest water use efficiency. The essential practice for making recommendations on the farm to reduce water losses is measuring, monitoring, and controlling flow at planning levels of the irrigation water, for having fair distribution.

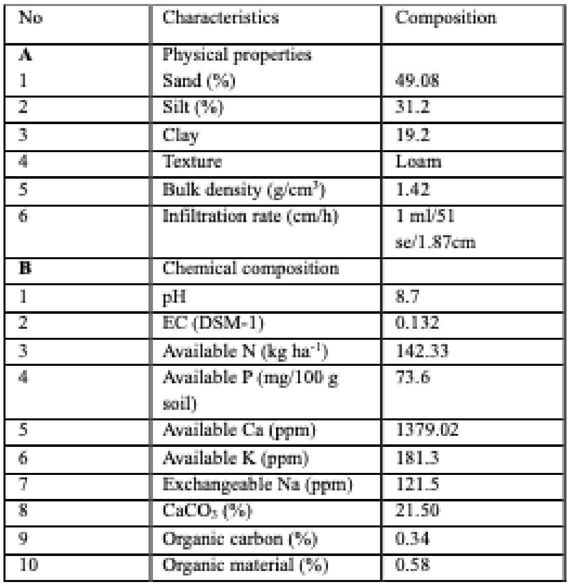
In this research on applying deficit irrigation at a specific time, growth stages were measured through observation and differentiation of growth stages. Bean growth stages determine by specific growth steps, such as vegetative (20 days) which was measured from germinating the 10 first plants in each treatment up to 10 early flowers in the same plot, flowering period (30 days) starting from at least 10 flowers in treatment up to at least 10 pods formed in the same treatment, the third phase of bean crop by the name of pod formation period (20 days) starts from 10 pods formed up to 10 pods filled with seeds; grain filling period (20 days) measured the same as the previous phases, recorded from first 10 pods filled with been seeds up to maturation period; and the last period (maturation (20days)) was measured from pods filled with grains until final harvest(Ali et al., 2007b; Alipoor, S., 2022).

The bean water requirement under the agro-climatic conditions of Kabul province was calculated at about 600 mm, and the amount of water applied to the treatments was varied, by growth stages and temperature, which raised the (ET/o) rate in the field. The amount of evapotranspiration during the growing season was calculated by the CROPWAT application and the raw data obtained from the meteorological directorate for the years 2021 and 2022.

TABLE II. DETERMINATION METHODS IMPLEMENTED FOR MEASURING THE SOIL'S PHYSICAL AND CHEMICAL PROPERTIES

No	Characteristics	Method
1	Textural class	Hydrometer
2	Infiltration rate (mm hr^{-1})	Ring infiltrometer
3	Bulk density (g/cm^3)	ARPRO Method
4	pH	pH meter (1:5)
5	EC	EC meters (1:10)
6	Available N (kg ha^{-1})	Kjeldohl
7	Available P (kg ha^{-1})	Olsen method
8	Available S (kg ha^{-1})	Turbidimeter
9	Available K (kg ha^{-1})	Flame Photometer
10	Exchangeable Na (kg ha^{-1})	Flame Photometer
11	$CaCO_3$ (%)	Titrate with NaOH
12	Organic carbon (%)	Walkley block (titration and colorimeter method)
13	Organic material (%)	

TABLE III. FIRST TRIAL (2021), SOIL PHYSICAL AND CHEMICAL COMPOSITION IN DETAIL



No	Characteristics	Composition
A	Physical properties	
1	Sand (%)	49.08
2	Silt (%)	31.2
3	Clay	19.2
4	Texture	Loam
5	Bulk density (g/cm^3)	1.42
6	Infiltration rate (cm/h)	1 ml/51 se/1.87cm
B	Chemical composition	
1	pH	8.7
2	EC (DSM-1)	0.132
3	Available N (kg ha^{-1})	142.33
4	Available P (mg/100 g soil)	73.6
5	Available Ca (ppm)	1379.02
6	Available K (ppm)	181.3
7	Exchangeable Na (ppm)	121.5
8	$CaCO_3$ (%)	21.50
9	Organic carbon (%)	0.34
10	Organic material (%)	0.58

TABLE IV. SECOND TRIAL (2021), SOIL PHYSICAL AND CHEMICAL COMPOSITION IN DETAIL

No	Characteristics	Composition
A	Physical properties	
1	Sand (%)	36.5
2	Silt (%)	28.2
3	Clay	35.3
4	Texture	Clay loam
5	Bulk density (g/cm^3)	1.23
6	Infiltration rate (cm/h)	1 ml/49 se/1.65cm
B	Chemical composition	
1	pH	8.6
2	EC (dsm^{-1})	0.123
3	Available N (kg ha^{-1})	141
4	Available P (mg/100 g soil)	76.3
5	Available Ca (ppm)	1389
6	Available K (ppm)	198
7	Exchangeable Na (ppm)	130.7
8	$CaCO_3$ (%)	20.50
9	Organic carbon (%)	0.57
10	Organic material (%)	0.98

CROPWAT Model Description

CROPWAT 8.0 is a decision-support computer program based on several equations, developed by FAO to calculate reference evapotranspiration (ET o), crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IR), using rainfall, soil, crop, and climate data (Smith et al., 2002). The program includes general data for various crop features, local climate, and soil properties, and helps improve irrigation schedules and the computation of scheme water supply for different crop patterns under irrigated and rainfed conditions. This software needs four types of data, such as climatic data, rainfall data, soil data, and crop data (Muñoz & Grieser, 2006). In this study, climatic data for two years (2021-2022) were gathered from the Kabul Meteorological Farm.

Crop water requirement versus irrigation requirement

Crop water requirement is the amount of water equal to what is lost from a cropped field by the ET and is expressed by the rate of ET in mm/day. Estimation of CWR is derived from crop evapotranspiration (ETc), which can be calculated by the following equation (Pereira et al., 2015)

$$ET_c = ET_0 \times K_c$$

Whereas ET0 is the reference evapotranspiration of the crop, and Kc is the crop coefficient, which is the ratio of the crop ET0 to ETc. Crop coefficient represents an integration of the effects of four essential qualities that differentiate the crop from reference grass, and it covers reflectance of the crop-soil surface, crop height, canopy resistance, and evaporation from the soil.

$$(TDstageI) \quad x \quad (ET_c \ stageI) = ETc$$

Due to the ET difference during the growth stages, the Kc for the crop will vary over the developing period, which can be divided into four distinct stages: initial, crop development, mid-season, and late season (Allen et al., 1998).

Irrigation requirement (IR) is one of the principal parameters for the planning, design, and operation of irrigation and water resource systems. Determining the capacity of an irrigation system is a parameter of prime importance in formulating the policy for optimal allocation of water resources, as well as in decision-making in the day-to-day operation and management of irrigation systems. Therefore, the net irrigation requirement of crops was calculated using the following equation:

$$IR_n = ET_c - (Pe + G_e + W_b) + LR_{mm}$$

Whe [illegible] mm), (ETc) as mentioned above shows the crop evapotranspiration (mm), (Pe) determines the effective dependable rainfall (mm), (Ge) refers to groundwater contribution from the water table (mm), (Wb) water stored in the soil at the beginning of each period (mm) and (LRmm) is leaching requirement (mm).

For providing the exact amount of water to meet crop water requirements, gross water requirement for irrigation was considered, which is the total quantity of water depleted for irrigation in the field, and calculated through consideration of net irrigation requirement, water application losses, and other wastes. Which is calculated by the following equation.

$$IR_g = IRn / E \times 100$$

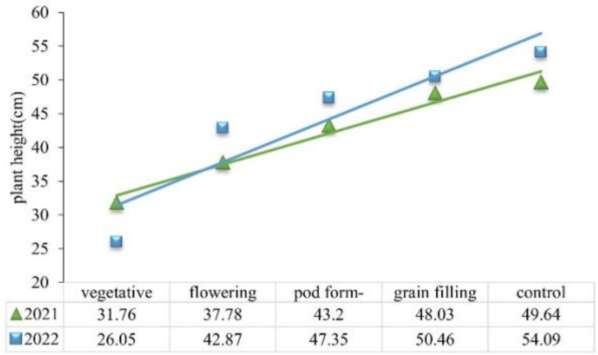
Whereas (IRg) is the gross irrigation requirement of the field, (IRn) is the net irrigation requirement, and (E) is the field efficiency of the system (Alipour, S., 2022).

III. RESULT

A. *Plant height*

The plant height response of common beans to the deficit application in different growth stages significantly ($P<0.05$) varied from CFI to Gd for both years (2021 and 2022) (Table 3.1). The treatments with full irrigation in all stages and deficit applications in the grain filling period (Gd) have achieved the highest record of plant height, compared to other treatments, and the treatment with deficit application in vegetative growth stages has shown the lowest record of plant height.

This trial explored that treatments with full irrigation and Gd significantly increased the height of bean plants, and did not show significant differences in deficit application at grain filling period and control treatments, while deficit applied in a vegetative period significantly reduced the plant height and the two other treatment also had a reduction in plant height but in compare to Vd, these treatments have better condition. This exhibited that there is a relationship between water stress and bean height. The slopes of the regression line provide reference values for plant height response to drought in various growth stages. Moreover, the sensitivity of plant height to drought conditions varied with growth stages (Figure 3.1).



	vegetative	flowering	pod form-	grain filling	control
▲2021	31.76	37.78	43.2	48.03	49.64
■2022	26.05	42.87	47.35	50.46	54.09

Fig. 1. Regression line shows relationship of capsoly bean plant height with deficit application in its growth stages by both years 2021 and 2022.

B. *Number of leaves per plant*

Deficient application was varied according to the growth stages of the capsule bean, which represented a significant ($P<0.05$) difference in the number of leaves per plant. The treatment with full irrigation significantly increased the number of leaves per plant compared to other treatments. Treatments with deficit application in vegetative, flowering, and pod formation periods exhibited significant differences with the control treatment in the number of leaves per plant for both years (Table 3.1). However, the treatment with deficit application in the grain filling period showed no significant reduction in the number of leaves per plant in both years.

The slope of the regression line provides reference values for plant leaves' responses to dry spells that occur in various growth stages. However, the sensitivity of the number of leaves per plant to drought conditions, expressed by the slopes of the regression lines, was different in different growth stages. Indeed, the results showed that the vegetative growth stage was the most sensitive stage to drought for the number of leaves per plant, and deficit irrigation significantly reduced the number of leaves per plant (Figure 3.2).

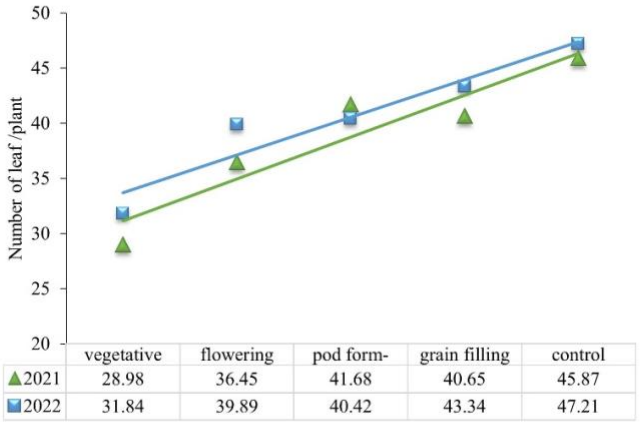


Fig. 2. Regression line shows relationship of number of leaves per plant with deficit application in different growth stages in both years.

C. *Number of branches per plant*

Capsoly bean, which is a local bean variety, indicated a significant (P<0.05) difference in the number of branches per plant in response to deficit application on different growth stages in 2021. The study showed that dry spell occurrence in vegetative growth, flowering, and pod formation stages significantly reduces the number of branches per plant of capsule beans compared to the other two treatments, such as full irrigation and deficit application at the grain filling period. However, the result for 2022 indicated no significant difference in the number of branches per plant among treatments. However, the highest number of branches per plant was recorded in the dry spell implemented in the grain-filling period in 2022. The regression line for 2022 explored the least relationship between water stress and the number of branches per plant in all treatments.

The regression line for 2021 revealed a deep relationship between the occurrence of dry spells and the number of branches per plant in Vd, Fd, and Pd treatments, while the number of branches per plant increased with deficit application in the grain filling period and full irrigation (Figure 3.3).

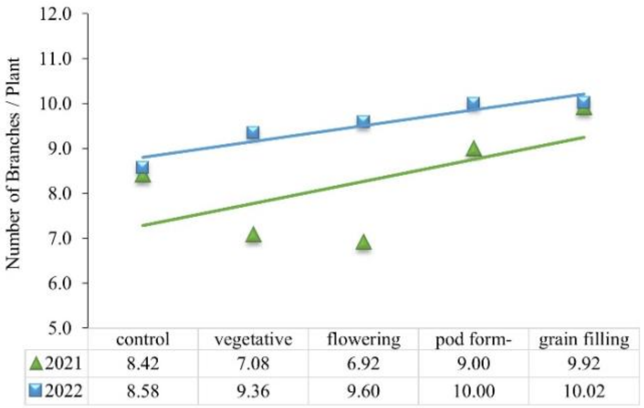


Fig. 3. Regression line shows relationship between number of branches per plant with deficit application in different growth stages in both years.

D. *Leaf area and leaf area index*

The effects of deficit application in different growth stages of capsule beans indicated significant differences in leaf area and leaf area index. In this study, CFI and Vd stages of Capsoly bean have revealed significant (P<0.05) differences in leaf area compared to Fd, Pd, and Gd, while exposing the flowering, pod formation, and grain filling period of Capsoly bean to drought stress significantly reduces the value of leaf area (Figure 3.4).

The regression line showed a close relationship between the occurrence of drought in growth stages and leaf area in capsule beans. The slopes of the regression line varied when applying drought at different growth stages. Indeed, the result shows that the capsule bean is more tolerant of vegetative growth stages to drought stress than other stages, as far as leaf area is concerned (Figure 3.4).

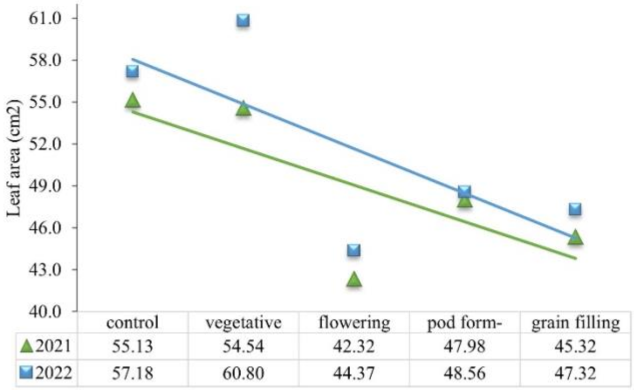


Fig. 4. Regression line shows relationship between leaf area and deficit application in different growth stages in both years.

TABLE VI. THE EFFECT OF A DRY SPELL ON THE LEAF AREA AND LEAF AREA INDEX OF THE CAPSULE BEAN

The leaf area index of the Capsoly bean shows no significant difference between treatments for drought stress. Treatment with drought applied in vegetative growth and full irrigation recorded the highest value of leaf area index compared to FD, PD, and GD. While treatment with drought applied in the flowering period showed a lower value of leaf area index (Figure 3.2). The regression line indicates no relationship between the leaf area index and the drought occurring in the growth stages of capsule beans. So, it indicated that the initial growth stages of bean crops are more tolerant to drought conditions than the flowering, pod formation, and grain filling periods in the leaf area index. The line shows that the flowering period is sensitive to leaf area index but isn't significantly affected. (Figure 3.4).

E. Number of pods per plant

This study revealed that drought occurrence at different growth stages significantly (P<0.05) affected the number of pods per plant. The treatments with full irrigation and GD have the highest record for several pods per plant, and the other treatments, such as VD, PD, and FD, show a lower value for several pods per plant.

Treatments CFI and GD indicated a significantly higher number of pods per plant, while no significant difference was observed between CFI and GD treatments. The treatments with drought occurrence at pod formation and flowering period have shown a significant reduction in the number of pods per plant, respectively (Table 3.4). The regression line shows the relationship between drought occurrence at growth stages and the number of pods per plant (Figure 3.5). The slopes of the regression line provide information about the response of several pods per plant to drought in various growth stages.

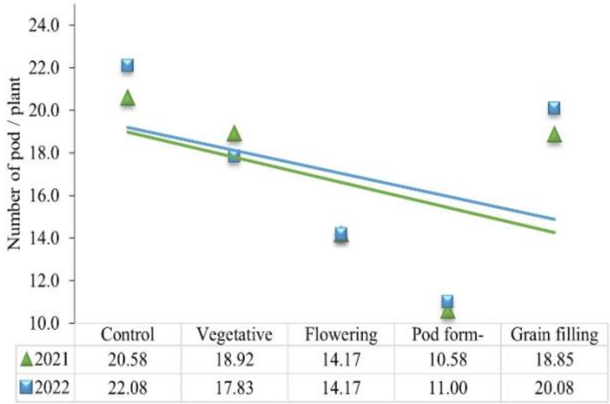


Fig. 5. Regression line shows relationship between number of pod /plant and drought occurrence in different growth stages.

F. Length of pod

In this trial, the result indicated that the length of pods significantly (P<0.05) differed among the treatments (Table 3.4). The highest record for pod length was observed in CFI, VD, and GD with 11.1 cm, 10.4 cm, and 10 cm in 2022, respectively. However, the treatments with drought application in the flowering and pod formation periods had the lowest length of pods in both years.

The regression line shows the relationship between drought occurrence in different growth stages and pod length. Slopes of the regression line show that drought occurrence in the flowering and pod formation periods affects the pod length of the bean crop is affected and the length of which is significantly reduced (Figure 3.6). This study shows that the flowering and pod formation period of the capsoly bean is more sensitive to drought conditions than other growth stages.

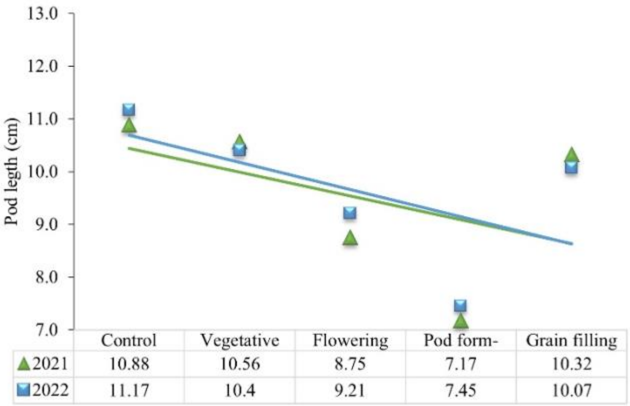


Fig. 6. Regression line shows relationship between length of the pod and drought occurrence in growth stages.

G. Number of grains per pod

The experiment indicated that drought application at different growth stages resulted in different numbers of seeds per pod, and the treatments with drought application at pod formation stages showed a significant reduction in the Number of grains per pod. The result showed that the full irrigation, vegetative, flowering, and grain-filling period of capsule beans by achieving the average of 4.5, 4.8, 3.5, and 4.2 seeds per pod was more tolerant than other periods in 2022, respectively (Table 3.4).

The slope of the regression line shows a negative relationship between drought occurrence at different growth stages and the number of seeds per pod. Drought occurred during the pod formation period significantly (P<0.05) and affected the number of grains per pod. The regression line indicates no significant difference among treatments in 2021 (Figure 3.7).

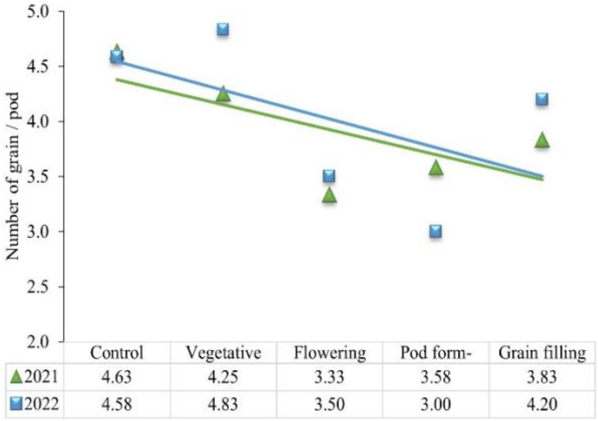


Fig. 7. Regression line shows relationship between number of seed per pod and drought occurrence in different growth stages.

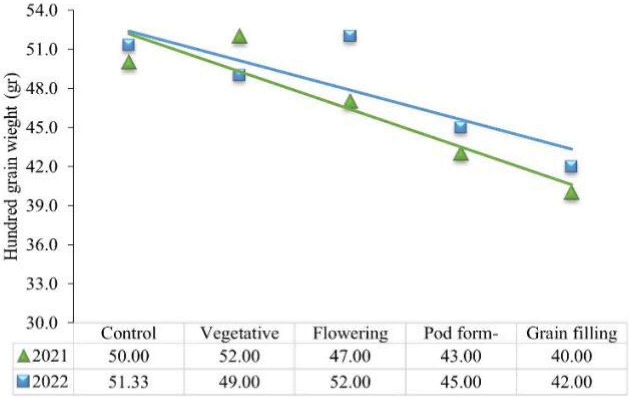
H. Hundred-grain weight

The research indicated that the hundred-seed weight due to the drought occurrence in different growth stages significantly (P<0.05) varied among the treatments.

The treatments with drought occurrence at vegetative and flowering periods and full irrigation by achieving 51, 49, and

52 recorded higher hundred-grain weights among the treatments, and the treatments with drought application at pod formation and grain filling periods have shown lower hundred-grain weights, respectively. The research revealed that flowering and vegetative periods faced drought conditions, but there was no significant difference from full irrigation.

The slope of the regression line shows the sensitivity rate of hundred-grain weight, which was different for drought application at different growth stages (Figure 3.8). The study revealed that the occurrence of drought during the grain filling and pod formation period shriveled the seeds and significantly reduced the hundred-grain weight.

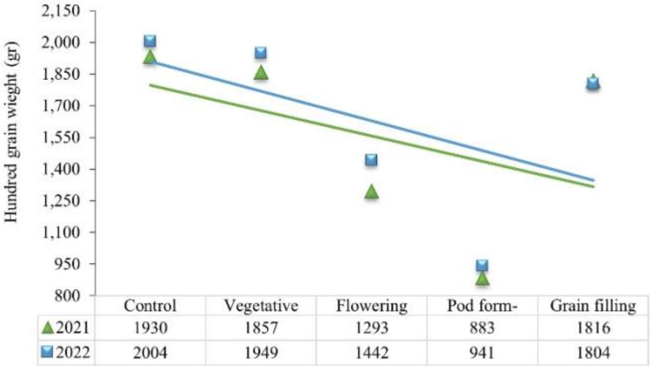


	Control	Vegetative	Flowering	Pod form-	Grain filling
▲2021	50.00	52.00	47.00	43.00	40.00
■2022	51.33	49.00	52.00	45.00	42.00

Fig. 8. Regression line shows relationship between hundred grain weight and drought occurrence in different growth stages.

I. *Grain yield*

In this study, the response of the grain yield of capsoly bean to drought application at different growth stages was significantly different among treatments. The research showed that full irrigation and drought application at vegetative and grain filling periods significantly affect the grain yield of capsoly beans, but the treatments with drought application at flowering and pod formation periods showed a significant reduction in the grain yield of capsoly beans (Table 3.9).



	Control	Vegetative	Flowering	Pod form-	Grain filling
▲2021	1930	1857	1293	883	1816
■2022	2004	1949	1442	941	1804

Fig. 9. Regression line shows relationship between grain yield and drought occurrence in different growth stages.

J. *Crop yield response factor (KY)*

The sensitivity and tolerance of the crop against stress are represented by the crop yield response factor (KY). An increase in KY value indicates crop sensitivity, and vice versa, a decrease in KY value shows the tolerance of crops. The study explored that capsoly bean is tolerance to drought occurrence at vegetative and grain filling periods due to in these treatments the KY found 0.03 and 0.1 respectively, but KY indicated that capsoly bean is more sensitive to severe drought stress at the flowering and pod formation period because drought occurrence in this period, extremely all the inflorescence and pod will fail, and significantly reduced the yield (Figure 3.10).

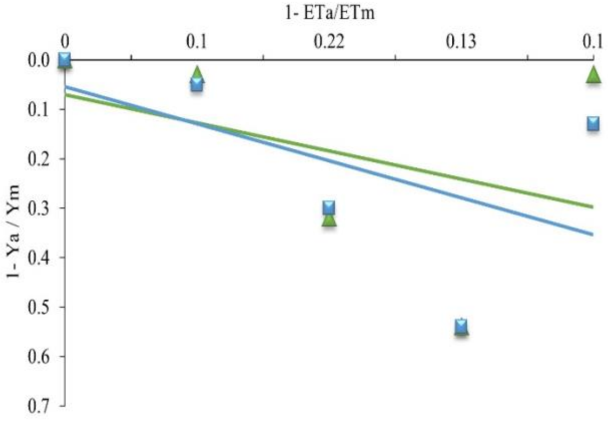


Fig. 10. Regression line shows the common bean yield response to relative deficit irrgation in 2021 and 2022.

TABLE VII. THE EFFECT OF DROUGHT APPLICATION ON SEVERAL PODS PER PLANT, THE LENGTH OF THE POD, AND THE NUMBER OF GRAINS PER POD OF THE CAPSULE BEAN.

Treatments	Pod /plant				Length of pod			Grain /pod		
	2021	2022			2021	2022		2021	2022	
C_{FI}	20.58	22.08			10.83	11.17		4.63	4.58	
V_D	18.92	17.83			10.56	10.40		4.25	4.83	
F_D	14.17*	14.17*			8.75*	9.22*		3.33	3.50	
P_D	10.58*	11.00*			7.17*	7.45*		3.58	3.00*	
G_D	18.85	20.08			10.31	10.07		3.83	4.20	
LSD	**5.93**	**7.21**			**2.05**	**1.87**		**1.73**	**1.23**	
CV%	**31%**	**34%**			**19%**	**18%**		**31%**	**31%**	

* Represent a significant difference from control (P<0.05). LSD least significant difference, and CV = Coefficient of Variation

IV. DISCUSSION

A. *GROWTH STAGES OF CAPSULE BEAN*

The experiment indicated that the effect of drought occurrence at different growth stages of bean crops was significantly varied. Treatments with drought occurrence at vegetative growth and grain filling periods did not show any significant difference from full irrigation in the duration of the growth period, and vice versa, the flowering and pod formation periods significantly shortened the length of growth periods due to drought occurrence. The vegetative period of the capsule bean was found to be resistant to two subsequent phases, such as flowering and pod formation periods (Alipour, 2022). The effect of drought on crops varies according to plant genotype, intensity, duration of stress, weather conditions, and growth stages of plants (Golezani Et al., 2010). Morphological and phonological traits such as plant type, root systems, and early flowering play a major role in the adaptation of plants to drought conditions.

Treatments with drought occurrence at flowering and pod formation showed a significant reduction in the duration of the flowering and pod formation period. Considering this result, the Bean crop is the most sensitive crop to drought occurrence at flowering and pod formation periods (Golezani Et al., 2010). The periods needed a larger amount of water for photosynthetic reactions and high physiological and chemical activities. Meanwhile, drought stress has a negative impact, such as excess production of Reactive Oxygen Species, which results in membrane lipid production, pigment discoloration, protein inactivation, and DNA injury in bean crop cells, which finally leads to cell death (Manjeru et al., 2007).

The bean crop has an antioxidant defense system, osmolytes, and secondary metabolites, which play an important role in bean crops during drought stress, but the problem is that the mechanism responds to slight drought stress (Kusvuran and Dasgan, 2017). The osmolytes system works as a compatible solute that adjusts the osmotic potential in the cytoplasm, and its contents can be used as a physiological marker of osmotic stress. Accumulation of glucosinolates is another factor that enhances the bean's tolerance to drought stress conditions, which is called a secondary metabolite appearing under low turgor pressure in tissue facing water stress (Alipour, 2022).

Finally, the experiment indicated that the drought occurrence significantly affects the growth periods of capsule beans. The higher value of the growing season has been recorded from treatments with full irrigation, drought occurrence at the vegetative period, and drought occurrence at the grain filling period, but the lowest growing season was recorded from drought occurrence at the flowering and pod formation periods. Treatments that imposed drought conditions at flowering and pod formation periods failed about 50% of their inflorescence and pods, respectively, and their leaves desiccated and fell during the maturation period, also causing pre-maturing of grain yield (Kumar et al., 2018)..

B. *Agronomical traits*

In this study, the application of drought on the growth stages of Capsoly bean for evaluating the effect of water deficit on agronomical traits resulted in the treatments with drought occurrence at pod formation and grain filling showing no significant difference with full irrigation in plant height, number of leaves per plant, and leaf area. A similar result was reported by Yazar et al. (2017), who found that full irrigation increased plant height, leaf area index, and more photosynthetically active leaves compared to other treatments. Application of drought during the grain filling period did not show any significant difference in the number of branches per plant, but drought occurrence during the vegetative growth and flowering period significantly reduced the plant height and number of leaves per plant. Drought stresses cause to increase in Auxins (Indole Acetic Acid, IAA) hormones that play essential roles in diverse developmental events such as root growth, vascular tissue differentiation, auxiliary bud formation, apical dominance, and flower organ development (Arbeu et al.,2011). Producing the free auxin through hydrolysis of inactive auxin IAR3 (IAA-Ala resistant3) is reported by Alipour (2022).

Water restriction significantly affects the leaf area of bean plants, which is highly sensitive to drought stress; this phenomenon leads to a reduction in nitrogen demand in the plants (Chanbari et al., 2013). This means that the reduction in leaf surface causes a decrease in the chlorophyll content and nitrogen in the plant leaf. Chlorophyll reduction correlated with a decrease in the photosynthesis reaction. This issue decreases the ability of leaves to provide food due to fewer chemical reactions.

Some researchers reported that water restriction reduces the hydraulic conductivity in the plants, which leads to a decrease in the nutrient supply to the shoot. Shoot growth limitation reduces the metabolic demand of plants necessary for osmotic adjustment, which prevents water loss from cells and maintains the turgor of the plants (Rao et al., 2016).

C. *Yield and yield component*

The study indicated that the treatments with full irrigation and drought occurrence at vegetative and grain-filling periods did not show any significant effect on the number of pods per plant, pod length, number of grains per pod, 100-grain weight, and grain yield of the bean crop compared to treatments with drought occurrence at flowering and pod formation periods. A similar result was reported by Alipour (2022), who found that full irrigation and drought occurrence at vegetative and grain filling treatments recorded a higher value of pod yield, and a lower total pod yield was obtained from treatments in which drought occurrence at flowering and pod formation periods occurred, compared to the full irrigation throughout the growing season.

Remobilization of carbohydrates from vegetative tissue, seed, and pod wall into the seed is not the same for plants that experience drought and fully irrigated plants, thereby reducing their capacity to maintain high yields under stress conditions (Manjeru et al., 2007). Reduction in seed weight due to reduced photosynthesis might also be the cause of reduced yield. Water stress during flowering reduces yield through increased flower failure and, to a lesser extent, by reducing the number of seeds per pod, as reported by white et al. (1994). The research explored that there was no significant difference between the grain yield, 100-grain weight, and number of grains per pod at treatments with drought occurrence at grain filling and vegetative periods, and full irrigation and no need for supplementary irrigation.

This experiment showed a positive correlation between grain yield and the number of pods per plant, indicating that pods per plant could be a reliable selection criterion for high-yielding bean genotypes evaluated under water stress. Increasing water at flowering and pod formation increases the number of grains per pod, 100-grain weight, and finally the yield of a bean crop. Alipour (2022) reported that increasing the amount of water in bean crops reduces the protein content, and vice versa, protein concentration increases in severe drought stress in bean crops

D. Crop Yield Response Factor (KY)

The crop yield response factor (KY) indicates the sensitivity of common beans to drought occurrence at flowering and pod formation periods and the tolerance of bean crops to drought occurrence at vegetative and grain filling periods during the growing season. A crop yield response factor (KY) greater than one means that a bean crop is sensitive to drought stress, and whenever the KY is lower than one, it shows the tolerance of a bean crop to water stress (Al-Omran and Louki, 2011). Common beans, by having an antioxidant defense system, osmolytes, and secondary metabolites, are more tolerant to slight drought stress at flowering and pod formation periods, while being more sensitive to severe drought stress at the mentioned periods. KY was found at 0.86 and 0.91 in treatments with drought occurrence at vegetative growth and grain filling periods, respectively, which contributed to the fact that bean crops received 86 % and 91 % of water during the growing season, and the yield of these treatments did not show any significant reduction from full irrigation.

V. DISCUSSION

a) Common bean (Phaseolus vulgaris L.) is a rich source of nutrients and is a precious gift to mankind, often known as the poor man's meat. This crop is the storehouse of multiple nutritional components that include protein (16-50%), dietary fiber about 10-23%, essential elements (Fe, Ca, Mg, Zn, and K), carbohydrates, sugar, and vitamins (Gargi et al., 2022). This crop is grown throughout the world as an important legume crop and is the major source of food for more than 300 million people around the world (Simsek, 2011).

b) The response of common beans to drought stress varied at different growth stages. Common beans tolerated drought stress at vegetative and grain filling periods, and the bean crop has shown the best performance in the number of pods per plant, length of pod, grain per pod, 100-grain weight, and total grain yield with the application of full irrigation and drought occurrence at vegetative and grain filling period treatments. In addition, drought occurrence at flowering and pod formation periods significantly reduced the mentioned parameters, especially leaf area and number of pods per plant.

The bean crop is more sensitive to severe drought stress, especially at flowering and pod formation periods. Drought negatively affects leaf area, inflorescence, and the number of pods of the plants; indeed, drought occurrence leads to restricting the leaf area expansion to decrease the photosynthesis reaction.

Regulated deficit irrigation is a best practice for water-scarce areas, particularly in Afghanistan, where water shortage is more common during the bean-growing season. It is recommended that the flowering and pod formation periods of the Capsoly bean are the most sensitive periods to drought stress and should never be faced with water stress. Therefore, the water saved from vegetative and grain filling periods can be used to irrigate the sensitive periods. Economic studies are highly recommended to evaluate their feasibility and to identify any constraints that might affect their implementation.

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