Cultivos Tropicales, Vol. 46, No. 1, January-March 2025, e-ISSN: 1819-4087, p-ISSN: 0258-5936, https://ediciones.inca.edu.cu

Cu-ID: https://cu-id.com/2050/v46n1e01

Original article

Answer of the bean's cultivation to hydric deficit in different moments of your biological cycle

Efecto del déficit hídrico en el suelo en diferentes etapas del crecimiento y desarrollo del cultivo del frijol

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ABSTRACT: The present work was carried out at the National Institute of Agricultural Sciences (INCA) with the objective of determining the response of bean crops (*Phaseolus vulgaris* L.) to water deficit applied at different stages of their biological cycle. For this purpose, seeds of Triunfo 70 variety were used, cultivated under semi-controlled conditions. The treatments used consisted of suspending water supply to the plants for 15 days during the vegetative growth, flowering, and grain filling stages, and a control group that was irrigated throughout the period with 100 % of the crop's standard evapotranspiration (ETc). The evaluations carried out were plant height, stem diameter, dry mass of the aerial part, leaf surface area, relative water content, soil moisture, relative chlorophyll content, number of pods per plant and grains per pod, 100-grain weight, grain size, and yield per plant, relative growth rates, absolute growth rates, net assimilation rates, and leaf area ratios were also determined. The results obtained allowed us to conclude that the suspension of irrigation during the grain filling stage is the least sensitive to soil water deficiency.

Key words: relative of water contained, chlorophylls, growth, yield.

RESUMEN: El presente trabajo se realizó en el Instituto Nacional de Ciencias Agrícolas (INCA) con el objetivo de determinar la respuesta del cultivo del frijol (*Phaseolus vulgaris* L.) al déficit hídrico aplicado en diferentes momentos de su ciclo biológico. Para ello se utilizaron semillas de la variedad Triunfo 70 cultivadas en condiciones semicontroladas. Los tratamientos utilizados consistieron en suspender el suministro de agua a las plantas durante 15 días en las etapas de crecimiento vegetativo, floración y llenado de grano y un control que se irrigó durante todo el período con el 100 % de la ETc. (evapotranspiración estándar del cultivo). Las evaluaciones realizadas fueron la altura de las plantas, diámetro de los tallos, masa seca de la parte aérea, superficie foliar, contenido relativo de agua, humedad del suelo, contenido relativo de clorofilas, el número vainas por planta y de granos por vaina, masa de 100 granos, el tamaño de los granos y el rendimiento por planta. También se determinaron las tasas relativas de crecimiento, absolutas, de asimilación neta y la relación de área foliar. Los resultados obtenidos permitieron concluir que la suspensión del riego en la etapa de llenado de grano, es la menos sensible a la deficiencia hídrica en el suelo.

Palabras clave: contenido relativo de agua, clorofilas, crecimiento, rendimiento.

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is the most consumed legume in the world because of its high protein and carbohydrate content. It is currently cultivated on all five continents and it is part of the diet of more than 300 million people (1).

Drought is a natural hazard that can cause serious impacts on the different socioeconomic sectors of a state or nation. It is capable of drastically disrupting human activities, social development and the environment, from which no country, no matter how developed, can completely escape (2).

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Received: 03/07/2023

Accepted: 05/04/2024

Conflict of interest: Authors declare that they have no conflict of interest.

Author contributions: Conceptualization- Donaldo Morales. **Research**- Donaldo Morales, Lilisbet Guerrero, Arasay Santa Cruz. **Supervision**- Donaldo Morales. **Initial draft writing**- Donaldo Morales, Lilisbet Guerrero, Arasay Santa Cruz. **Final writing and editing**- Donaldo Morales, **Data curation**- Donaldo Morales

Sixty percent of the world's bean production is obtained under water deficit conditions, and this factor is the second most important contributor to yield reduction after diseases.

Water stress is a physiological response of plants to the decrease of available water in the environment, which results in an imbalance between transpiration and water absorption (3).

Plant's response to water stress is immediate. Growth is affected due to the loss of turgor that affects the reduction of cell volume and increase of solutes that generate cellular mechanical damage that can affect growth reduction (4).

Water deficit is one of the environmental factors that most affects plant growth and development. Under water stress conditions, growth decreases proportionally to the severity and magnitude of the stress condition and, if the stress is not lethal and remains stable for a period, the plant can recover (5).

It has been shown that water relations, growth, yield per plant, bean mass and bean size are affected by the presence of soil water deficit in the vegetative and reproductive stages of different bean varieties (6).

In recent times, there are many works related to water deficit in bean cultivation, but very few have addressed the study of its effect on the different stages of growth and development of the plant, that is, not all stages have been addressed in the same work.

Therefore, the present work has been carried out with the objective of determining the response of the bean crop to water deficit applied at different times of its biological cycle.

MATERIALS AND METHODS

The present work was carried out at the National Institute of Agricultural Sciences (INCA) located at 22º58′00″N and 82°09′00″W and 138 m a.s.l. For this purpose, 12 concrete containers of 2.60 m long by 0.60 m wide (1.56 m^2) containing Ferrallitic Red Leached soil from Mayabeque province (7) an area that is part of the Havana-Matanzas karst plain (8) were used.

In each container, bean seeds of Triunfo 70 variety were sown in two rows with a separation between them of 0.40 m and 0.10 m between plants (52 plants per container).

Treatments used consisted of suspending irrigation (SR) for 15 days at different times, in the vegetative growth stage from 15 to 30 days after planting (VG). The other one in which the suspension was made from 30 to 45 days (FG), another with suspension of irrigation from 50 to 65 days (GF) and a control treatment in which the plants were supplied throughout the period with 100 % ETc (standard evapotranspiration of the crop).

Irrigation was applied by an automated micro-sprinkler system and water delivery was controlled by valves conveniently was placed on the irrigation laterals of each treatment. The pH and electrical conductivity values of the water applied to the crop during the experiment were 7.8 and 0.58 dS m, respectively.

To avoid the effect of precipitation or dew, during the irrigation suspension period, a transparent nylon blanket was placed over and without making contact with plants.

Irrigations consisted of replenishing the daily standard crop evapotranspiration (ETc) three times per week (Monday, Wednesday and Friday). Plants before and after suspension of irrigation (SR) received 100 % of ETc.

Each container received 1 kg of cow manure to improve fertility and substrate structure.

Reference evapotranspiration ETo (mm), standard crop evapotranspiration ETc (mm) and irrigation requirements (ETc= ETo$\ast$Kc) were obtained using the CropWat.8 program. This program was updated with a historical series of meteorological data for 31 years (1990- 2021) corresponding to Tapaste meteorological station belonging to the National Institute of Meteorology, approximately 200 m from the experimental site, and monthly mean values were used to calculate ETo and ETc.

The crop coefficients (Kc) used were initial Kc = 0.26, average Kc= 1.08 and final Kc= 0.52 (9).

Growth evaluations, soil moisture, relative water content and total chlorophyll were carried out at 30, 45 and 65 days after sowing (DAS) coinciding with the culmination of the irrigation suspension periods in the vegetative growth (VG), flowering (FG) and grain filling (GF) stages.

For the determinations of relative water content, total chlorophylls (SPAD) and growth, ten replicates per treatment were taken.

Evaluations consisted of determining some issues such as: soil moisture, relative water content at 7 hours of sunlight and before applying replenishment irrigation. Besides some other were studied like length and diameter of stems, dry mass of stems, leaves and aerial part, leaf area, relative, absolute and net assimilation rates and leaf area ratio, total chlorophyll content in SPAD units, number of pods per plant and number of grains per pod, mass of 100 grains, grain dimensions and yield per plant.

Growth relationships were determined by the functional method (10).

A randomized block design with three replications was used, 10 plants were taken from each replication (30 per treatment).

Data analysis was performed using the Statgraphics Plus 5 statistical package and means were compared using the Least Significant Difference test or Tukey's multiple range test, as appropriate, and Sigma Plot 11 was used to plot the data.

RESULTS AND DISCUSSION

As shown in Figure 1, in all cases, soil moisture in the treatments in which irrigation was suspended for 15 days decreased significantly, with values even lower than 50 % of those reached in the control treatment (100 % ETc).

This moisture behavior allows us to affirm that the plants were subjected to moderate to severe stress during this period.

Another indicator evaluated to characterize the presence of water stress was the determination of the relative water content measured between 7:00 h and 8:00 h at the end of each irrigation suspension period.

This indicator expresses the level of water in the tissues with respect to the total that can be stored when this liquid is in optimal availability conditions in the substrate in which the plant develops.

By observing Figure 2, it can be seen that the plants were indeed subjected to a strong water deficiency by showing values below 50 % of the water content in relation to that which can be reached when they are at full turgor.

The values found indicate that the plants were subjected to a strong water stress during the period when irrigation was suspended, which is in agreement with the results found when analyzing the behavior of soil moisture.

Other authors have reported similar results when they have subjected plants of this crop to different levels of soil moisture and treated with different biostimulants (11) and have served for the characterization of elite coffee plants for their tolerance to drought (12).

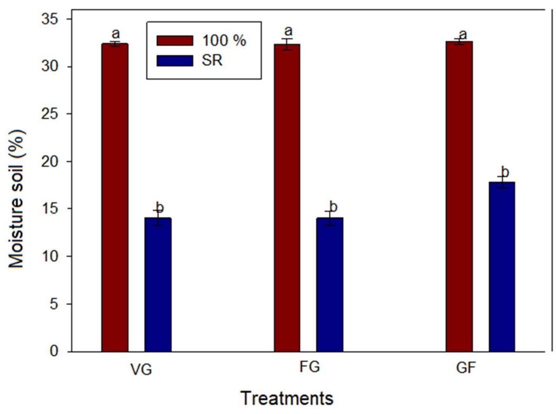
Table 1 shows the dimensions of stems, dry masses of stems, leaves, aerial part and leaf area. It can be seen that the variables related to stem growth did not differ from the control treatment in any of the variants used, which could indicate that the stress period was not long enough to achieve a significant differentiation between treatments. However, both the dry mass of the leaves and the aerial part of the treatments with irrigation suspension did differ from the control treatment, which is related to the accumulation of photoassimilates in this processing organ, which has a direct and significant impact on the behavior of these variables.

This response indicates that the dry mass of the aerial part was determined by the dry mass of the leaves. Other authors have reported a similar behavior of the dry mass of the stems when evaluating the effect of the application of some biostimulants together with nitrogen fertilizers (13).

On the other hand, leaf area, although it only showed statistically significant differences when irrigation was suspended between 50 and 65 days. It can be noted that in the remaining experimental variants the absolute values reached in the treatments with irrigation suspension reflect a strong depression of this variable. A response that could be associated with a decrease in leaf size, aspects that have been pointed out in works where the behavior of the relative water content has been related to leaf size (14).

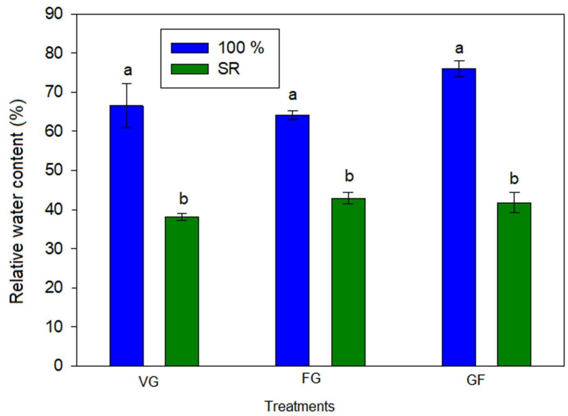
At the end of each irrigation suspension period (Table 2), the following growth ratios were analyzed: Relative Growth Rate (RGR), Absolute Growth Rate (AGR), Net Assimilation Rate (NAR) and Leaf Area Ratio (LAR).

It was observed that the lowest rates were reached in the treatments in which irrigation was suspended during the vegetative phases (15-30 days) and flowering stage (30-45 days), which confirms the sensitivity of the plant growth process to water deficiency; however, when the suspension was carried out during the grain filling stage (when plants had practically reached their maximum growth).



Bars above the columns correspond to the standard errors of the means and different letters indicate significant differences between treatments for α ≤ 0.05 according to the MDS (Minimum Significant Difference) test

Figure 1. Soil moisture at the end of the irrigation suspension (SR) periods for 15 days at the vegetative growth (VG), flowering (FG) and grain filling (GF) stages



Bars above the columns correspond to the standard errors of the means and different letters indicate significant differences between treatments for α ≤ 0.05 according to the MDS (Minimum Significant Difference) test

Figure 2. Relative water content at the end of the irrigation suspension (SR) periods for 15 days at the vegetative growth (VG), flowering (FG) and grain filling (GF) stages

The values obtained were higher than found in the stages mentioned above, although lower than when irrigation was not interrupted.

On the other hand, RAF showed the highest values in plants that at some point were subjected to water deficiency. The highest absolute values were observed in the treatments in which the suspensions were carried out in the youngest stages of the plants, a response that agrees with the results found by other authors (15).

Figure 3 shows that the only difference between treatments was found when the suspension was carried out at the grain filling stage.

Table 1. Effect of DRC treatments on the three developmental stages of bean (Phaseolus vulgaris L.) plants on different morphology indicators

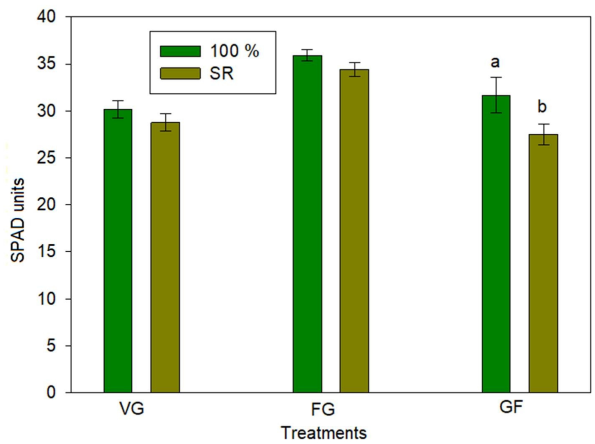
Treatments	Stem length (cm)	Stem diameter (mm)	Stem dry mass (g)	Dry mass of leaves (g)	Aerial dry mass (g)	Leaf area (cm^2)
100 % ETc	14.56	4.00	0.44	3.09 a	3.99 a	1312.04
Suspension between 15 and 30 days	13.06	3.20	0.39	1.63 b	2.03 b	995.54
MDS	1.57	0.27	0.11	0.09	0.18	111.25
100 % ETc	37.02	4.20	1.20	4.94 a	6.07 a	2158.83
Suspension between 30 and 45 days	35.00	3.80	1.12	2.79 b	4.02 b	1759.15
MDS	2.85	0.30	0.08	0.17	0.20	139.93
100 % ETc	59.60	6.80	2.61	12.67a	15.27 a	3698.19 a
Suspension between 50 and 65 days	55.20	6.40	1.87	6.93b	8.80 b	2244.73 b
MDS	6.68	0.55	0.31	1.20	1.25	400.18

Different letters mean significant differences between treatments for $\alpha \leq 0.05$ according to the MDS (Minimum Significant Difference) test

Table 2. Relative and absolute rates of growth, net assimilation and leaf area ratio in bean plants (Phaseolus vulgaris L.) at the end of the irrigation suspension period

Treatments	RGR (g g day^{-1})	AGR (g day^{-1})	NAR (g cm^{-2} day^{-1})	LAR (cm2 g^{-1})
100 % ETc	2.81 a	15.26 a	125.58 a	121.66 c
Suspension between 15 and 30 days	0.89 d	2.24 c	15.36 c	216.94 a
Suspension between 30 and 45 days	1.29 c	3.77 c	28.14 c	204.79 a
Suspension between 50 and 65 days	2.03 b	8.27 b	66.13 b	166.38 ab
Se $\bar{X}$	0.07	0.90	8.32	15.36

Different letters mean significant differences between treatments for $p \leq 0.05$ according to Tukey. RGR = Relative Growth Rate, AGR = Absolute Growth Rate, NAR = Net Assimilation Rate and RAF = Leaf Area Ratio



Bars above the columns correspond to the standard errors of the means and different letters indicate significant differences between treatments for α ≤ 0.05 according to the MDS (Minimum Significant Difference) test

Figure 3. Total chlorophyll contents at the end of the 15-day irrigation suspension (IR) periods at the vegetative growth (VG), flowering (FG) and grain filling (GF) stages

The concentration of photosynthetic pigments is related to the foliar concentration of nitrogen, so that in an indirect way it is possible to know the deficiency or excess of this element, which can serve as a technical basis to suggest the adequate management of the crop, in order to enhance the photosynthetic efficiency, quality and yield (16).

This result indicates that plants in general were sufficiently supplied with nutrients, mainly nitrogen. Its availability did not constitute a limiting factor for their normal growth and development, a response that agrees with those reported in studies where this variable was evaluated in bean plants grown with different levels of soil moisture and treated with foliar applications of a biostimulant (17).

From this result, it can be inferred that the photosynthetic system of the leaves maintained its integrity, which guaranteed favorable conditions for plant development.

The response found when irrigation was suspended at the grain filling stage could be associated with the age of the plant and the acceleration of the leaf senescence process caused by the water deficiency at a more advanced age stage as an evasion mechanism in the face of the stress condition.

This decrease in chlorophyll content could be attributed to a possible inhibition of the synthesis of this pigment due to the age of the plant together with the activation of its degradation by the enzyme chlorophyllase (18).

Table 3 shows the analysis of yield and its components. First, it can be seen that the treatments used had no effect on the number of beans per pod or on the mass of 100 beans, while the number of pods was significantly affected by the irrigation suspensions, with the one made during the flowering stage being the one that limited this variable largely. Other authors have reported that water deficiency in the soil during the flowering period and the beginning of bean formation reduced yield per plant (19).

On the other hand, when evaluating bean size by length, width and thickness, it was noted that the treatment in which

Table 3. Yield and its components of bean (Phaseolus vulgaris L.) plants subjected to irrigation suspensions at different times of their biological cycle

Treatments	Pods per plant	Grains per pod	Mass of 100 grains (g)	Length of grains (mm)	Grain width (mm)	Grain thickness (mm)	Yield per plant (g)
100 % ETc	9.23 a	6.30	2018	9.64 a	6.26 a	4.35 a	11.72 a
Suspension between 15 and 30 days	7.96 b	6.48	19.96	9.68 a	6.36 a	4.51 a	9.83 bc
Suspension between 30 and 45 days	7.08 c	6.60	19.62	9.46 a	6.33 a	4.60 s	9.25 c
Suspension between 50 and 65 days	8.06 b	6.50	19.56	9.18 b	5.82 b	3.93 b	10.20 b
SE $\bar{X}$	0.09	0.11	0.22	0.09	0.05	0.06	0.26

Different letters mean significant differences between treatments for $p \leq 0.05$ according to Tukey

irrigation was suspended at the bean filling stage was the only one that caused a significant decrease in bean size. It led to a lower yield than the treatment without irrigation suspension, an aspect that must be related to a lower capacity of the plant to achieve full growth of the cells that make up the bean. The bean dimensions found in this work agree with those reported by other authors when evaluating the behavior of this variable in commercial beans under Mexican conditions (20).

It is well known that a water deficiency in the soil affects the different processes that ultimately determine plant productivity, such as gas exchange characterized by stomatal conductance and carbon assimilation, as well as transpiration. It plays an important role in the absorption of nutrients and their movement through the plant, aspects that can explain the behavior shown by plants grown under the conditions mentioned above (21).

Finally, the yield per plant was significantly affected when the suspension of irrigation was carried out during the flowering stage, followed in order by the suspension in the vegetative stage, and although without differing with this treatment, the suspension was carried out in the grain filling stage, resulting the suspension in this stage the one that least affected the yield.

The lack of water in the soil caused a significant decrease in yields of different bean varieties compared to those that were well-irrigated, results that are confirmed by those reported in this work (22).

This slight difference in yield between plants with suspension of irrigation at the stage of grain filling with respect to the well-irrigated treatment is interesting in two directions. The first in that it defines this stage as the least sensitive to water deficiency and the other in according to other authors, under such conditions increases the synthesis of metabolites with the ability to inhibit the synthesis of some of the enzymes involved with the metabolism of carbohydrates, resulting in obtaining bean seeds with a greater hypoglycemic effect (23).

CONCLUSIONS

In conclusion, the suspension of irrigation for 15 days during the vegetative growth, flowering and bean filling stages of bean plants of Triunfo 70 variety caused a water deficiency in the soil that had a negative effect on the relative water content, dry matter accumulation in the aerial part, growth relations and yield. Particularly the suspension during the grain-filling period affected leaf area, total chlorophyll content and grain size.

RECOMMENDATIONS

These results suggest that, in a situation of water shortage for irrigation or other inconveniences that require water saving, the most advisable variant is to apply 100 % of the ETc during the vegetative growth and flowering phases and to suspend irrigation during the grain-filling phase.

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