Recital
Revista de Educação,
Ciência e Tecnologia de Almenara/MG.

PRODUCTIVE PERFORMANCE OF MUNG BEAN LINES UNDER IRRIGATION LEVELS

Desempenho produtivo de linhagens de feijão-mungo sob diferentes lâminas de irrigação

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DOI: https://doi.org/10.46636/recital.v6i3.586

Abstract

The mung bean (*Vigna radiata* (L.) Wilczek) is a grain from the fabaceae family rich in protein, fiber and minerals. Widely consumed in Asia, it is sown in various parts of the world, especially India. Despite its potential, the average yield is around 500 kg ha^{-1} compared to the potential of 2,000 kg ha^{-1}. The aim of the study was to evaluate the effect of water deficit on the performance of mung beans. The experiment was carried out at Embrapa Meio-Norte, using a randomized block design with subdivided plots. In the plots, five irrigation levels were evaluated (40, 70, 100, 130 and 160% of ETc) and, in the sub-plots, two mung bean lines (M19 and M20), with four replications. The imposition of the lowest water levels (40 and 70% of ETc) resulted in significant differences in all the variables studied. There was a 43% reduction in grain yield between the highest levelL160 and the lowest L40. The application of the smallest blade of irrigation L40 (133 mm) of water resulted in a grain yield of 482 kg ha^{-1}. In contrast, the application of the highest irrigation level, L160 (357 mm), resulted in an average grain yield of 1,117 kg ha^{-1}.

Keywords: *Vigna radiata*. Irrigation. Grain yield.

Resumo

O feijão-mungo (*Vigna radiata* (L.) Wilczek) é um grão da família das fabáceas rico em proteínas, fibras e minerais. Amplamente consumido na Ásia, é semeado em diversas partes do mundo, com destaque para a Índia. Apesar de seu potencial, a produtividade média está em torno de 500 kg ha-1 em comparação com o potencial de 2.000 kg ha^{-1}. O estudo teve por objetivo avaliar o efeito do deficit hídrico sobre o desempenho do feijão-mungo. O experimento foi realizado na Embrapa Meio-Norte, utilizando-se delineamento em blocos casualisados no esquema de parcelas subdivididas. Nas parcelas, avaliaram-se cinco lâminas de irrigação (40, 70, 100, 130 e 160% da ETc) e, nas subparcelas, duas linhagens de feijão-mungo (M19 e M20), com quatro repetições. A imposição das menores lâminas (40 e 70% da ETc) resultou em diferenças significativas em todas as variáveis estudadas. Registrou-se uma redução de 43% na produtividade de grãos entre a maior lâmina L160 e a menor L40. A aplicação da menor lâmina de irrigação L40 (133 mm), resultou em uma produtividade de grãos de 482 kg ha^{-1}. Em contraste, a imposição da maior lâmina de irrigação L160 (357 mm), proporcionou uma produtividade média de grãos de 1.117 kg ha^{-1}.

Keywords: *Vigna radiata*. Irrigação. Produtividade de grãos.

INTRODUCTION

The green mungbean (*Vigna radiata* (L.) Wilczek) is a small bean from the fabaceae family, called mungbean, green gram, fríjol mungo or moyashi bean in many parts of the world (Chen *et al*., 2022; Snak; Delgado-Salinas, 2023).

Despite the potential importance of mung beans, productivity has been low as a result of the social and physical environments in which the crop is grown. In Asia, East Africa and Australia, the average yield of mung bean is estimated at 500 kg ha^{-1} compared to the potential yield of 2,000 kg ha^{-1} (Chauhan; Willians, 2018), which means that it is still far below the achievable potential. Low yield is attributed to biotic and abiotic stresses, inadequate management techniques and limited access to improved varieties (Rachaputi, *et al*., 2015). The adoption of improved production technologies is an important strategy to address these challenges (Mmbando *et al*., 2021).

Research carried out in Santa Catarina and Minas Gerais has found average yields of between 400 and 2000 kg ha^{-1} (Lin; Alves, 2002; Vieira *et al.,* 2011). However, mung beans can be adapted to various rainfed and irrigated cultivation systems, providing farmers with increased income. Knowledge of the ideal water levels for mung beans is very important, both for the physiological and productive performance of the plant. Studies indicate that the crop's water requirement during its life cycle is between 100 and 400 mm (Pannu; Singh, 1993; Raza *et al.*, 2012; El-Nakhlawy *et al.,* 2018; Pereira *et al.*, 2019; Gölgül *et al.,* 2022).

Irrigation applied in the early stages of plant development provides grain production efficiency (Bastos *et al*., 2011; Islam *et al.,* 2021). According to Rahim, *et al*. (2014), increasing irrigation levels has a significant impact on grain yield, up to certain levels. Since the application of increasing levels can result in water wastage (Andrade Júnior *et al.,* 2018).

Therefore, studies on the use of different irrigation levels are necessary to determine the crop's water requirements. This study evaluated the productive performance of mung beans under different irrigation levels in the soil and climate conditions of Teresina, Piauí.

1 LITERATURE REVIEW

1.1 ORIGIN, DISPERSAL AND BOTANICAL ASPECTS

The mung bean (*Vigna radiata* (L.) Wilczek) has its diversity centered in Central Asia, but India is considered the main center of origin and domestication (Singh, 2013). From India, it spread to Asia, Africa, the Middle East and the Americas (Huppertz *et al.*, 2023), being cultivated in tropical and subtropical countries (Rachaputi *et al.*, 2019).

Mung beans are erect or semi-erect, with a height of 0.3 to 1.5 m and stems, branches and leaves covered in hair. Flowering begins between 25 and 42 days after emergence and lasts several days, depending on the cultivar and planting conditions (Miranda *et al*., 1997). The flowers are light yellow or greenish and pollinated by insects, resulting in cylindrical pods of 7 to 15 cm covered in hairs.

The number of pods per plant varies from 4 to 34, depending on the planting density and environmental conditions. At maturity, the dry pods are brown or black and contain between 6 and 20 grains (Singh *et al.*, 2013). The grains are small, measuring 3.1 to 6.3 mm in length and 2.3 to 4.5 mm in width, and can be yellow, green, black, mottled or brown, all with a white hilum. The weight of 100 grains varies from 1.6 to 7.9 g (Lin; Alves, 2002).

1.2 SOCIO-ECONOMIC IMPORTANCE OF MUNG BEANS

The global area under mungbean cultivation is around 7.3 million hectares, and production is around 5.3 million tons. India and Myanmar account for around 30% of this production, China for 16% and Indonesia for 5%. There is currently a growing demand for mung beans worldwide (Instituto Brasileiro de Feijão e Pulses, 2023). To meet this demand, farmers need to improve the efficiency and effectiveness with which they manage the crop (Pasley *et al.*, 2023).

This legume has aroused interest among Brazilian farmers, as it is hardy, resistant to pests and diseases and occupies the land for a short time, as well as providing opportunities for niche vegetarian and vegan markets (Duque *et al.*, 1987; Yanos; Leal, 2020; Carbonell *et al.,* 2021, Noleto et *al.,* 2023).

For the commercial production of this legume, it is very common to use genotypes with green seeds, which contain between 9.5 and 31.2% protein, 10.6% water, 4.4% fiber, 1.2% lipids and 3.5% minerals such as Ca, P, Fe, Na and K (Shrestha, *et al.,* 2023).

The family tradition, cultivation techniques, hardiness and nutritional contribution of the mungo, make it an essential element in the diet of many people. This is why this species plays an important role in ensuring global food security.

1.3 IRRIGATION LEVELS AND HYDRIC DEMAND

Irrigation plays a crucial role in agriculture, as it provides water for plants when natural rainfall is discontinuous and insufficient to meet the plants water needs (Sosiawan *et al*., 2021). In some cases, water is a limiting factor. Therefore, it is important to plan irrigation management to increase yield and efficient water use (Souza *et al.,* 2019). Selecting more productive and water-efficient cultivars can lead to better economic and environmental gains (Gölgül *et al.,* 2022).

Current irrigated mung bean production has been the subject of scientific research, with studies examining irrigation methods and practices to optimize yield. For example, a study conducted by Silva *et al*. (2019) evaluated the effect of applying different levels of water on mung bean grain yield. The results revealed that the application of water in the initial phase of cultivation increased the crop's yield. A study on the effects of nitrogen doses and irrigation levels on mung beans was carried out by Pereira *et al*. (2019). These authors found that the optimum water levels for mung beans are between 50 and 70% of the soil's field capacity. Values above 70% do not generally favor the plant's vegetative growth.

Proper water management during the early stages of mungbean cultivation is essential. Germination and the initial development of seedlings are critical moments that require an adequate amount of water. However, exact water requirements can vary depending on several factors, such as climatic conditions, soil type and agricultural management practices (Chauhan; Williams, 2018; Nair *et al.,* 2019). If water is scarce, irrigation needs to be planned to ensure that plants have enough water for germination and initial growth without wasting it (Islam *et al*., 2024). Studies carried out in Pakistan evaluated the effects of irrigation levels on the growth and productivity of mung beans. The authors found that the application of five irrigations, at 15, 30, 45, 60 and 75 days after sowing, provided significantly better performance than three, four or six irrigations applied (Raza *et al*., 2012).

Islam *et al*. (2021) researched the physiological and biochemical changes in mung beans in response to different irrigation regimes. They recorded a variation of 169 to 277 mm in the applied water levels and that treatments irrigated in two or three phases had significantly higher yields than those that received irrigation in just one phase.

Studies indicate that the volume of water required for responses in the development and production of mungo is between 150 and 300 mm, throughout the phenological stages (Pannu; Singhh *et al*., 1993, Bastos *et al,* 2011; Islam *et al.,* 2021). In the period of grain formation and maturation, water demand decreases and the crop may require around 50 to 100 mm. These figures are general estimates and can vary considerably based on local conditions. El-Nakhlawylam *et al*. (2018) in a study on the efficiency of irrigation water use through low consumption during the plant's growth phases, recorded blades of 290 mm (applied in the vegetative period) to 320 mm (leveldistributed throughout the crop cycle). Correct irrigation management allows farmers to mitigate the negative effects of water stress or soil waterlogging, which can significantly affect crop production (Bag *et al*., 2020).

2 MATERIALS AND METHODS

2.1 CHARACTERISTICS OF THE STUDY AREA AND EXPERIMENTAL SETUP

The experiment was conducted between July and October 2022, in the Experimental Fields Sector of the Brazilian Agricultural Research Corporation (Embrapa Meio-Norte), in the municipality of Teresina, Piauí (05°05' S. 42°48' W and 74.5 m); 42°48' W and 74.4 m). The soil at the site is classified as Argissolo Vermelho-Amarelo distrófico, with a sandy loam texture (0-30 cm) and sandy loam from 30-60 cm, with a slope of 0% to 3% (Melo; Andrade Júnior; Pessoa, 2014). The chemical and physical-hydrological characteristics of the soil are shown in Table 1.

Table 1. Physical-chemical-water characterization of the soil in the experimental area. Teresina-PI, 2022.

	MO	**pH**	**P**	**K**	**Mg**	**Ca**	**Na**	**CEC**	**V**
Depth (m)	g kg^{-1}	H O_2	Mg mg^{-3}			$cmol_c$ dm^{-3}			%
0.0-0,3	12.9	5.8	31.1	0.09	0.35	0.78	0.02	2.94	42.3
0.3-0,6	11.2	5.9	23.5	0.09	0.42	0.73	0.02	2.89	44.1

Layers (m)	**Density (g cm^{-3})**	**Sand**	**Silt**	**Clay**	**Θ fc**	**Θ p w p**
		------------------------g Kg^{-1} --------------------			**(% volume)**	
0.0-0.3	1.70	876.5	37.5	86.0	21.7	5.3
0.3-0.6	1.65	811.5	52.5	136.0	20.8	6.0

Source: Soil Laboratory of the Brazilian Agricultural Research Corporation (EMBRAPA Meio-Norte). OM = organic matter; CEC: cation exchange capacity; V = base saturation; Θcc = moisture at field capacity; Θpmp = moisture at permanent wilting point.

According to the Köppen classification, the regional climate is tropical dry (Aw), with two well-defined seasons, dry in winter and rainy in summer, with periods of drought during the rainy season (veranicos). The average annual air temperature is 30 ºC and rainfall is 1200 mm. The climate data recorded during the trial (July to September 2022) and on an annual basis is shown in Table 2. During the experiment, the average air temperature was 31.6 ºC, the relative humidity was 50.6% and the accumulated rainfall was 10.8 mm.

Table 2. Average weather data obtained during cultivation (July to September 2022) and annual data (January to December 2022)[1]. Teresina-PI, 2022.

Meteorological elements	**During cultivation**	**Annual data**
Total rainfall (mm)	10.8	1.336
Relative humidity (%)	50.6	72.6
Average air temperature (ºC)	31.6	27.1

Source: INMET, 2023[1]

The treatments were arranged in subdivided plots. In the plots, five irrigation levels were used (corresponding to 40%, 70%, 100%, 130% or 160% of the reference evapotranspiration - ETc), and in the sub-plots, two mung bean lines (M19 or M20). The experiment was conducted in a randomized block design with four replications.

The pre-commercial mung bean lines were obtained from Embrapa Meio-Norte's germplasm bank. The lines are part of a macro-breeding program at Embrapa Meio-Norte. The experimental plots consisted of an area measuring 4.0 m x 6.0 m, totaling 24 m^2, made up of eight rows spaced 0.5 m apart. The four central rows were considered the useful area (10 m2).

2.2 SOWING AND CULTIVATION

The seeds were sown on July 20, 2022, using the SEMEATO® SHP 249 experimental planter. 20 seeds per meter were distributed in rows spaced 50 cm apart. At the time of planting, 600 kg ha^{-1} of N, 135 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O from the 5-30-15 formula were applied. This fertilization was based on the results of the soil analysis and the recommendations of the Embrapa Meio-Norte soil and fertilization manual for cowpeas.

The weeds were controlled with pre-emergence spraying of the herbicides Gramoxone® (2 L ha^{-1}) + Dual gold® (2 L ha^{-1}). Post-emergence, to control grasses, the systemic selective herbicide Selec 240 EC® was applied at a dose of 450 ml ha^{-1} mixed in the spray tank with the vegetable oil adjuvant aureus® at a ratio of 0.5% v/v.

2.3 MANAGEMENT AND IRRIGATION SYSTEMS

The irrigation levels were applied using a fixed conventional sprinkler system, with sprinklers arranged at a spacing of 12 x 12 m, with nozzles measuring 3.4 x 2.6 mm in diameter and a flow level of 1.07 m^3 h^{-1} at a working pressure of 20 m.c.a. A 12 m strip was left between the plots to avoid the influence of one sheet of water on another from the neighboring plot.

The lines received irrigation levels corresponding to 100% of crop evapotranspiration (ETc) until 22 days after planting (DAP). From that date onwards, the five water levels were applied: L40 = 40% of ETc, L70 = 70% of ETc, L100 = 100% of ETc, L130 = 130% of ETc and L160 = 160% of ETc. The Penman-Monteith FAO method was used to determine ETo (Allen *et al*., 1998). This method is based on climatic data collected at an agrometeorological station located at Embrapa Meio-Norte's headquarters, approximately 1 km from the experimental area.

Irrigations were carried out on Monday, Wednesday and Friday. On Monday, the accumulated ETc from Friday, Saturday and Sunday was applied; on Wednesday, the accumulated ETc from Monday and Tuesday and on Friday, the accumulated ETc from Wednesday and Thursday. To measure the uniformity of water distribution applied in each water regime, five batteries of 16 thermoplastic collectors measuring 80 x 102 mm (80 collectors in total) were installed in a 12 x 12 m grid between four sprinklers in the central part of the experimental area.

2.4 SOIL WATER MONITORING

The water content in the soil was monitored by moisture sensors at the depths of 0.0 to 0.3 m and 0.3 to 0.6 m in each water regime. The aim of this monitoring was to find out about the availability of water in the soil. Soil moisture and PAR radiation data were recorded on several dataloggers distributed throughout the experimental units. The data was collected weekly using a notebook.

2.5 COLLECTION AND STATISTICAL ANALYSIS

The crop was harvested manually on September 23, 2022, at 65 DAP. To do this, the useful area of the plots were delimited, then the plants were harvested and placed in raffia bags. After drying and removing the pods, the following variables were quantified:

1 - Number of pods per plant (NPP): determined on 10 plants picked at random from the useful area of each plot;

2 - Pod length (PL): determined on 10 pods taken at random from 10 plants, using a graduated ruler and the result expressed in centimeters (cm).

3 - Number of grains per pod (NGP): determined from the 10 pods taken at random from the 10 plants in the useful area of each plot.

4 - weight of 100 grains (W100G): determined from 10 pods taken at random from 10 plants in the useful area of each plot, weighed on a properly regulated precision scale and the result expressed in grams (g).

5 - Grain yield (GY): After threshing the pods of all the plants in the useful area, the weight of the grains was measured on a precision scale, correcting the humidity to 13%, and the values expressed in Kg ha^{-1}.

The tabulated and systematized data were submitted separatelly to analysis of variance using the "F" test and the means were compared using the Tukey test at the 1% probability level. The irrigation levels were evaluated by regression analysis using the R software® (R Core Team, 2016). The output data was plotted using Excel graphics and SigmaPlot® (ver. 11.0, Systat Software Inc., San Jose, CA, USA).

3 RESULTS AND DISCUSSION

3.1 IRRIGATION MANAGEMENT AND LEVELS

Rainfall provided 10.8 mm, while the total amount applied ranged from 133.8 mm at L40 to 357.0 mm at L160. The average contribution of rainfall in relation to the total level applied was 4.3%, which did not compromise the levels of water deficiency in the soil programmed with the planned differentiation. It was observed that in the crop phase most sensitive to water deficit, from flowering to grain filling (FL-EG), 45.9 mm and 74.2 mm were applied at L40 and L70, while 103.2 mm and 146 mm were applied at L100 and L160, respectively (Table 3).

Table 3. Planned and total irrigation levels applied at each phenological stage of the mung bean: S-E (Sowing-emergence), DV (vegetative development), FL-FV (flowering - pod formation), FV-EG (pod formation - grain filling), M-C (ripening - harvest). Teresina-PI.

Internship	**Irrigation level (mm)**					**Total level (mm)**				
	40	**70**	**100**	**130**	**160**	**40**	**70**	**100**	**130**	**160**
	ETc	**ETc**	**ETc**	**ETc**	**ETc**	**ETc**	**ETc**	**ETc**	**ETc**	**ETc**
S-E	30.1	30.1	30.1	30.1	30.1	40.9	40.9	40.9	40.9	40.9
E-DV	33.3	42.4	51.4	59.7	68.6	44.1	53.2	62.2	70.5	79.4
DV-FL	20.9	37.8	54.7	69.8	86.5	31.7	48.6	65.5	80.6	97.3
FL-EG	35.1	63.4	92.4	120.9	146	45.9	74.2	103	131.7	156.8
M-C	3.6	7.3	9.6	12.3	15	14.4	18.1	20.4	23.1	25.8
Cycle	**123**	**180.9**	**238.2**	**292.7**	**346**	**133.8**	**192**	**249**	**303.5**	**357**

Irrigation is essential for mung bean production, especially in regions where water deficit can limit plant growth and productivity. Studies indicate that water use efficiency, growth and yield of mungbean are influenced by different irrigation regimes (Pannu; Singhh *et al.*, 1993; Bastos *et al.,* 2011; Rahim et al., 2014; Pereira et *al.,* 2019; Bag *et al.*, 2020; Islam *et al.*, 2021; Gölgül et al., 2022; Mahajan *et al.*, 2023). For example, a study carried out in India with mung beans showed that water use increased with irrigation frequency. Using longer intervals between irrigations significantly reduced water consumption. This is essential in regions where water is scarce or expensive, as it allows for a more efficient allocation of water resources. Despite being less frequent, irrigation every 300 mm resulted in higher yields compared to irrigation every 200 mm. This suggests that, the crop responds better to an irrigation regime that promotes mild water stress, rather than being constantly supplied with water. The increase in yield is associated with positive physiological processes, such as flowering, pod development and greater water use efficiency (Pannu; Singh, 1993). It is important to note that, the response of plants to irrigation varies with growth stage and soil type, so it is necessary to adjust irrigation practices according to local conditions and the specific characteristics of the mung bean variety (Raza *et al.*, 2012). For efficient irrigation management, it is recommended to monitor soil water conditions, climate, and plant demands, adjusting irrigation to optimize both water use and crop productivity (El-Nakhlawylam *et al.,* 2018).

By implementing efficient irrigation techniques and optimizing water use, farmers can not only improve mung bean productivity, but also conserve water resources and reduce environmental impacts (Islam *et al*., 2024). This is due to the precocity of the plant and the varieties used or found? in a given planting location (Sosiawanl, *et al.,* 2021).

3.2 PRODUCTION COMPONENTS AND GRAIN YIELD

The analysis of variance indicated that the production components, pod length (PL), number of grains / pod (NGP), number of pods / plant (NPP), weight of 100 grains (W100G) and grain yield (GY), responded significantly to the irrigation level (LAM) factors. The interaction between leveland lines was not significant. The coefficients of variation (CV's) ranged from 3.44 to 15.28%, indicating excellent precision in the results obtained (Table 4).

Table 4: Summary of the analyses of variance for the production components and grain yield (GY) in response to the water regimes applied. LAM: applied blade; LIN: lines; CV: coefficient of variation; PL: pod length; NGP: number of grains / pod; W100G: weight of one hundred grains; NPP: number of pods per plant; GY: grain yield corrected to 13% moisture. Teresina-PI, 2022.

FV	**GL**	**PL**		**NGP**	**NPP**	**W100G**		**GY**	
LAM	4	5.0571	***	22.250 **	4.6441 *	10.450	***	399395.1	***
Block	3	0.4223		2.000	0.2856	1.2687		6073.00	
Error a	12	0.0921		4.750	1.2408	1.9150		9574.44	
LIN	1	0.0640	ns	0.400 ns	7.8322 ns	0.2722	ns	29346.59	ns
LAM*LIN	4	0.6334	ns	0.350 ns	1.3441 ns	1.5790	ns	4349.46	ns
Error b	15	0.8534		6.520	1.798	4.7437		7717.56	
Total	39								
CV-Lam (%)		3.44		5.63	7.74	5.63		15.28	
CV-Lin (%)		4.71		7.92	5.70	7.92		14.81	

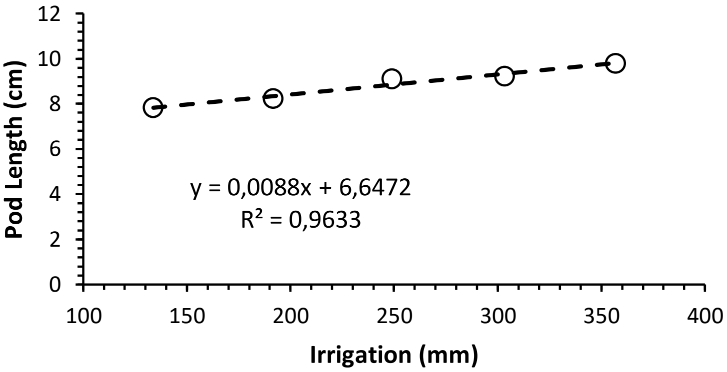
Significance levels using the F test: ns: No significant (p>0.5); *: Significant (0.5≥p>0.010); **: Significant (0.01≥p>0.001); ***: Significant (p≤0.001).

3.2.1 POD LENGTH (PL)

Figure 1 shows a coefficient of determination (R^2) of 0.9633, which indicates that approximately 96.33% of the variation in pod length can be explained by the variation in irrigation levels applied. This means that as the irrigation level increases, pod length also tends to increase linearly.

Pod length ranged from 7.8 to 9.8 cm, corresponding to blades L40 and L160, respectively (Figure 1). The average pod length was 9.0 cm. The results for this parameter are in line with the observations of Alves *et al.* (2018), when they assessed the correlation between production components and grain yield of mung bean lines in Nova Ubiratã-MT. The authors found pod length averages of 9.06 cm for lineage 20 and 9.09 cm for lineage 19. Pod length averages of around 9.2 cm were obtained by Canci; Toker (2014), evaluating yield components of 19 mung bean genotypes in floodplains in Turkey. Higher pod growth levels are probably due to the greater availability of photosynthetic pigments in the reproductive phase and the greater efficiency in the use of solar radiation in these stages (Teixeira et al., 2015).

Figure 1. Pod length (PL) of two mung bean lines as a function of increasing irrigation levels. Teresina, PI, 2022.

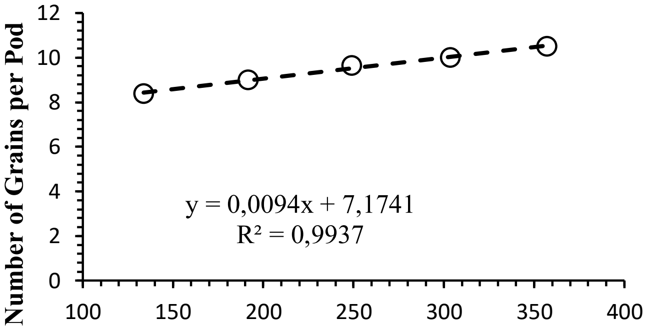


Silva *et al.* (2019), analyzing the production and development of mung beans as a function of population densities of 200,000 and 400,000 plants ha^{-1} in Ipameri, Goiás, found that there was no influence of plant density on pod length, which stood at 9.05 cm. On the other hand, Sharma *et al.* (2016) recorded pod lengths of between 3.1-4.1 cm for some mungo lines. According to the authors, this reduction was due to the high temperatures (40 ºC, reaching close to 45 ºC) to which the lines were subjected. High temperatures with low vapor pressure deficits increase the level of transpiration, causing a decline in soil moisture, which can induce water and heat stress simultaneously. The decrease in pod length under conditions of water deficit causes a reduction in the number of grains per pod, which has a direct impact on grain yield. Pannu and Singh (1991) observed average values ranging from 4.90 to 6.03 cm, with the application of 150 to 300 mm of water. According to Bezerra *et al.* (2014), the production component pod length is more related to the genetic characteristics of the cultivar than to elements associated with the environment.

3.2.2 NUMBER OF GRAINS PER POD (NGP)

Figure 2 shows a coefficient of determination of (R^2 =0.9937), indicating an increasing linear trend, i.e. almost all the variation in the number of grains per pod can be explained by variations in the irrigation levels applied. It suggests that there is a strong positive correlation (r=0.47) between the irrigation levels applied and the NGP variable. The result for the number of grains per pod (NGP) corresponded to a variation of 10.5 to 8.4 grains per pod, representing a 25% reduction between the highest level L160 and the lowest L40. This was in line with the research by Pannu; Singh (1993) with the application of a 300 mm water table. With this water imposition, the authors observed 10.5 grains per pod, resulting in a yield of 1,141 kgha^{-1}.

Figure 2**.** Number of grains per pod (NGP) of two mung bean lines as a function of increasing irrigation levels. Teresina, PI, 2022



Christian *et al.* (2023) recorded NGP values of 9.81 to 11.57. Bag *et al.* (2020) observed that there was no significant effect for the NGP component between irrigation regime treatments, due to the different sowing dates and irrigation schedules. They recorded a maximum value of 11.8 and a minimum of 11.7 grains per pod. Statistical analysis of the data from the study by Raza *et al.* (2012) revealed that irrigation levels had no significant effect on the number of grains per pod. However, the maximum number of grains per pod (6.61) was obtained in T_2 with 5 irrigations, and the minimum (5.48) was recorded in the control treatment. Islam *et al.* (2024) conducting research with eight mung bean genotypes (four susceptible to drought and four tolerant) and two moisture conditions, observed values of 6.1 and 3.7 grains per pod for the well-watered and water deficit conditions, respectively. One of the factors for this reduction in NGP is the low moisture content of the soil, which affects the plants water potential and chlorophyll content, the most important factor for grain development.

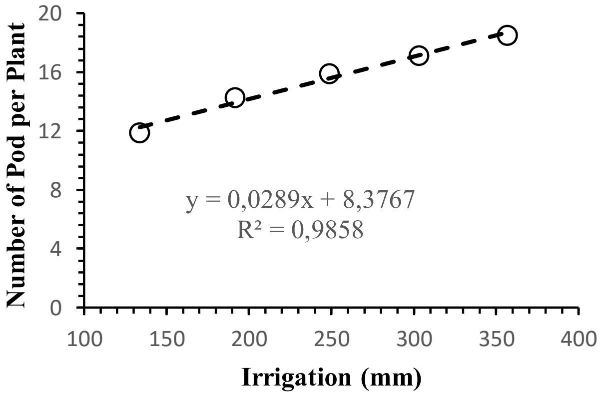
Sadeghipour (2008), evaluating the effect of suspending irrigation at different growth stages on the yield and yield components of mung bean varieties in Tehran, Iran, found that the average number of grains per pod was reduced from 17.2 to 9.3 due to the effect of suspending irrigation at all growth stages, the effect being most severe at the reproductive stage. Bastos *et al.* (2011) also found a sharp reduction in the number of grains per pod in cowpeas at the flowering stage, caused mainly by flower abortion.

The productive capacity of the mung bean plant is ultimately determined by the number of grains/seed, which is a key component of legume productivity.

3.2.3 NUMBER OF PODS PER PLANT (NPP)

Figure 3 shows a strong upward linear trend, and that almost all the variation in the number of pods per plant can be explained by variations in the irrigation levels applied (R^2 =0.9858). The number of pods per plant (NPP) as a function of the irrigation levels applied to the experimental plots showed a variation of 11.9 to 18.5 for the volumes applied of 133.8 to 357 mm, respectively. Similar results were verified by Gölgül *et al.* (2022), who recorded values of 8.9 to 18.9 for NPP, with the application of blades ranging from 126 and 445 mm, respectively. Another study that is in line with the results presented was that by Pannu; Singh (1993), when they studied the effect of irrigation levels on the growth and grain yield of mung beans and found that the number of pods per plant ranged from 8.3 to 15.5, this higher value resulting from the application of a 300 mm blade. Islam *et al.* (2024) investigated the response of mung bean genotypes to irrigation in different phenophases, with the aim of overcoming water stress and improving production in Dinajpur, Bangladesh, and found NPP of 5.2 for the water deficit condition and 7.8 for well irrigated. The decrease in water availability resulted in a reduction in the number of pods per plant and consequently in grain yield.

Figure 3 Number of pods per plant (NPP) of two mung bean lines as a function of increasing irrigation levels. Teresina, PI, 2022.



A divergent result was found by El-Nakhlawy *et al.* (2018) when studying three water regimes (100% of ETc; 70% of ETc in the vegetative stage; 70% of ETc in the reproductive stage), where they found values of 20.9 and 27.1 for the mung bean cultivars MNF and MN96, respectively. Rahim *et al.* (2014) investigating the effect of deficit irrigation and sowing methods on mung bean productivity, observed a variation in NPP from 20.9 to 27.0 for treatments I0 and I100, respectively.

Christian *et al.* (2023) observed values of 28.7 for the number of pods per plant with the OK2000 variety. Their study showed that the OK2000 mung bean variety, with its high productivity, would be ideal for commercial production. Similarly, Bag *et al.* (2020) also found that NPP was significantly affected by the different levels of irrigation. The imposition of 75% water resulted in 56.8 pods per plant.

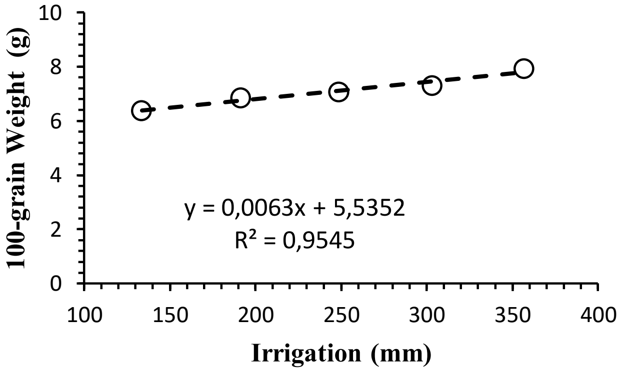
Raza *et al.* (2012), investigating the effects of different levels of irrigation on the growth and productivity of mung beans, recorded NPP values ranging from 33.3 to 47. Despite the high number of pods recorded by the authors, yields ranged from 588 kg ha^{-1} to 1,013 kg ha^{-1} for the control (no irrigation) and irrigated treatments. Similar yields to the present study. Yield and its components are influenced by several factors, including mung bean varieties, environmental conditions in the growing areas and agricultural practices. Therefore, the number of pods per plant is an important determinant of productivity and crop growth. More pods per plant are associated with higher yield potential (Bag *et al*., 2020; Islam *et al.,* 2024).

3.2.4 WEIGHT OF 100 GRAINS (W100G)

The results for the weight of 100 grains (W100G) are shown, in Figure 4. There was an increase in this component as the application of irrigation levels differed. There was a variation from 6.38 to 7.93 g. A decrease in grain weight in mung bean genotypes and varieties was reported by Sadeghipour (2008), Lin; Alves (2012), Canci; Toker (2014), Gölgül *et al*. (2022). Similar results were obtained by Ratnasekera; Subhashi (2015), when they examined the morphophysiological response of three mung bean genotypes in Sri Lanka under water stress. The authors observed values ranging from 6.02 to 8.32 g for the treatments imposing water stress in the vegetative phase and the control (full irrigation).

El-Nakhlawy *et al*. (2018) also reported a range of 5.84 to 8.17 g for treatments W3 (70% of total irrigation water requirements applied at flowering and W1 (100% of water requirements at all stages). Gölgül *et al*. (2022) in their study found no significant difference for W100G, but reported that treatment I0 (rainfed treatment - plants received no irrigation) provided the highest W100G value (8.85 g) among the treatments evaluated. The higher hundred-grain weights of treatments I_0 were the result of the stress-induced reduction in the number of pods and the number of grains.

Figure 4**:** Weight of one hundred grains (W100G) of two mung bean lines as a function of increasing irrigation levels. Teresina, PI, 2022.

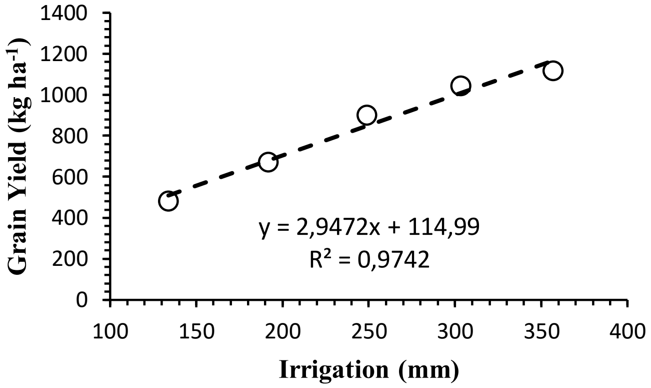


In contrast, a study by Islam *et al*. (2024) found that the condition of water stress notably decreased the weight of 100 grains among mung bean genotypes inconsistently; they recorded a range of 5.83 to 4.67 g for the BMX-05001 genotype, with treatments under conditions of moisture close to field capacity and critical moisture, respectively. Rahim *et al*. (2014) aiming to study the effect of different irrigations on the yield and production components of mungbean in Peshawar, Pakistan, reported that irrigation level I_{67} (67%) provided the highest value of 4.8 g for W100G, followed by the other irrigation levels of I_{100}, I_{33} and I_0 . These results suggest that modelevel irrigation, neither complete nor very restricted, was more effective for the weight of 100 grains in these circumstances. This result can be attributed to a variety of factors, such as the plant's efficient use of water and the balance between the availability of water and other resources for optimal growth. The optimized response at level I_{67} may indicate that mung beans have a certain tolerance to water deficits and that intermediate levels of irrigation may promote more efficient grain development. Grain weight is a variable of great importance, as it is generally used to calculate sowing density and to assess grain quality, maturity and health (Brasil, 2009). Therefore, this increase in grain weight in response to an increase in the irrigation level represents an important characteristic in studies of irrigated crops.

3.2.5 GRAIN YIELD (GY)

There was no significant interaction between irrigation level and cultivars for the grain yield variable. However, the decrease in water availability in the soil significantly reduced the productivity of mung beans (Figure 5). The following averages were recorded for GY: 482 kg ha^{-1} (L40), 672 kg kg ha^{-1} (L70), 901 kg ha^{-1} (L100), 1,043 kg ha^{-1} (L130), and 1,117 kg kg ha^{-1} for L160, with the application of 133.8, 191.7, 249, 303 and 357 mm, respectively. According to the results presented, there was a 43% reduction in grain yield between the highest levelL160 and the lowest L40. The highest yield in this study was 1,187 kg ha^{-1} for the M19 strain, with the application of 357 mm (L160).

Figure 5. Grain yield (GY) of two mung bean lines as a function of increasing irrigation levels. Teresina, PI, 2022.



The results obtained corroborate the findings of Islam *et al.* (2024), who found a 56% reduction in grain yield in all mung bean genotypes, indicating that water deficit stress has a negative effect on plant production. A 52.5% reduction in grain yield was also recorded by (Islam *et al.*, 2021), who reported yields ranging from 555 kg ha^{-1} for the treatment without irrigation to 1,145 kg ha^{-1} for the treatment with the application of a 277 mm blade. Sadeghipour (2018), in his study, found significant differences for grain yield. He recorded a sharp 61.4% reduction in grain yield when water deficit was imposed at the flowering stage. They found that the highest grain yield (1,425 kg ha^{-1}) was observed in the variety with irrigation throughout the growth period, and the lowest grain yield (532.70 kg ha^{-1}) was from the treatment without irrigation at the flowering stage. Raza *et al.* (2012) also investigated the effects of irrigation levels on the productivity of mung beans, where they observed that the lowest grain yield of 588 kg ha^{-1} was obtained in the control (no irrigation) and the highest yield of 1,634 kg ha^{-1} was recorded in the T2 treatment with 5 irrigations. Therefore, obtaining good yields of mungbean is essential and is increasingly sought after by grain producers. A previous study that is in line with this was by Lin; Alves (2012), when they studied the behavior of mung bean lines in Santa Catarina, where they recorded average yields of 1,015 to 1,085 kg ha^{-1}.

Rahim *et al*. (2014) found that grain yield was significantly affected by both irrigation and sowing method. The maximum grain yield of 1,429 kg kg ha^{-1} was obtained from irrigation level I67 (67% blade), followed by yields of 1,343, 1,084 and 687 kg ha^{-1} for irrigation levels I100, I33 and I0, respectively. This resulted in a 41% reduction in grain yield between the lowest and highest average yields. The hypothesis of Pannu; Singh (1993) revealed that irrigation with 300 mm tank evaporation is more beneficial in terms of water savings and productivity than frequent irrigation with 200 mm tank evaporation. The authors found a 47.9% reduction in grain yield between the highest yield (1,608 ha^{-1}) and the lowest (837 kg ha^{-1}).

Research by Gölgül *et al*., (2022), carried out at an average altitude of 1094, with the aim of determining the response of mung beans to water stress, observed grain yield values of 977 kg ha^{-1} for treatment I25 (25% of the water table applied) and 1,630 kg ha^{-1} for I_{100} (100% of the water table applied). However, higher yields were reported by Duque *et al*. (1987) in a preliminary study on the behavior of 21 mung bean cultivars in Itaguaí-RJ, where they recorded GY ranging from 1,300 to 1,700 kg ha^{-1}. These yields were influenced by a density of 500,000 plants per hectare, inoculation of rhizobium lines and the use of chicken manure at a level of 12 tons per hectare. And by El-Nakhlawy *et al*. (2018), who reported yields of 890 to 1,990 kg ha^{-1} for treatments with the imposition of water deficit at flowering (40 to 60 days after sowing) and full irrigation, respectively.

In India, Bag *et al*. (2020), aiming to select the optimum sowing date and irrigation frequency for mung bean cultivation in an alluvial zone, found an average yield of 1,446.70 kg ha^{-1} for treatment I4 (full irrigation) and 1,724.10 kg ha^{-1} for treatment I1 (rainfed). These values reflect the cultivar's high number of pods per plant (62 pods) and biomass. Grain yield per unit area is a function of the individual yield components which are influenced by crop management and the environment.

CONCLUSIONS

The reduction in water availability in the soil resulted in a decrease in all the components of production and productivity.

There was no significant difference in grain yield between the two mungo lines. The application of 249 mm of water (L100) was enough to achieve a satisfactory yield (1,043 kg ha^{-1}), representing a balance between saving water and maximizing yields.

Levels higher than 100% of ETc (such as L130 and L160) did not result in proportional gains in productivity, indicating that excessive irrigation may be unnecessary.

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Received on: *24 of June 2024*

Accepted on: *19 of February 2025*