E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(2): 252-258
Received: 11-12-2023
Accepted: 19-01-2024

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Analysis of growth indices of seven mothbean genotypes as affected by supplemental irrigation under water limiting environment

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i2d.313

Abstract
Drought stress during critical stages of growth i.e. before the onset of flowering is major detrimental factor for mothbean cultivation in arid and semiarid regions. Therefore, experiment was conducted to assess the effect of supplemental irrigation on physiology and growth characteristics of seven contrasting genotypes of mothbean, *viz*. RMO-257, RMO-40, RMB-25, RMO-2251, CZM-45 RMO-225 and RMO-435 under two environments i.e. rainfed (RF) and supplemental irrigation (SI, one irrigation applied at 30 days after sowing (DAS) i.e. before flowering) condition. Results showed that SI significantly increased shoot biomass, chlorophyll content and growth characteristics i.e. leaf area index (LAI), leaf area duration (LAD), net assimilation rate (NAR) and crop growth rate (CGR) as compared to RF condition in mothbean genotypes. Genotype RMO-257 performed better in terms of biomass accumulation and growth traits under RF condition whereas RMO-40 performed well under SI condition as compared to other genotypes. Hence, selection of genotypes and irrigation at critical crop growth stage proved to be beneficial for mothbean cultivation under area of limited water availability.

Keywords: Mothbean, drought, rainfed, supplemental irrigation, growth traits

Introduction

Abiotic stresses are one of the major constraints to crop production and food security worldwide. It has been estimated that 51-82% of the potential yield of annual crops is lost due to abiotic stress. Furthermore, various environmental stresses affecting plant growth and development have attained a serious concern in the context of possible climate change. Among the abiotic stresses, water deficit is an important threat to plant growth and sustainable agriculture worldwide (Fahad *et al*., 2017) [8]. Water deficit has appeared as a great menace to successful crop production in wake of changing climate. Drought stress is also accompanied with other biotic and abiotic stresses including salinity, heat stress and pathogen attack (Ahluwalia *et al*., 2021) [1]. Water deficit stress affects growth and photosynthetic efficiency which ultimately decreases the yield of the crop. Crucial changes in water status leads to molecular damage, growth inhibition and even death of tissues/ organs (Anjum *et al*., 2011) [2].

Mothbean is an important pulse crop of arid and semi-arid zones of Rajasthan, generally grown in water scarce conditions and mainly depends on rainfall. Rising temperature and uneven rainfall caused by climate change are making dry regions drier and leads to poor yield of mothbean in hot arid region (Garg and Burman, 2002) [9]. These crops often encounter drought situation during their vegetative and reproductive stages that reduces productivity to a large extent. Under such situation, replacing rainfed cropping systems with irrigated systems has been proved to be an effective strategy to increase upto 43% of the global agricultural production (Okada *et al*., 2018) [20]. Irrigation practices must be precise in drier areas as water scarcity is a major problem for crop cultivation. For this supplemental irrigation, which is a climate resilient practice of addition of less amount of water to essentially rainfed crops when rainfall is insufficient for normal plant growth, in order to improve and stabilize yields, proved to be beneficial. Supplemental irrigation during critical growth stages or most sensitive crop growth stages (mainly reproductive stage) helps in achieving maximum water use efficiency under rainfed condition (Kukal *et al*., 2014) [17]. Furthermore, in most rainfed ecosystems, single supplemental irrigation can increase the 50% average yield of the crop (Sharma *et al*., 2010) [24].

Improving crop growth under drought stress in field condition is one of the major concerns in hot and arid areas. Supplemental irrigation using limited amount of water increases the WUE and overall growth of the plant. Growth characteristics are functions of a large number of metabolic processes, which are affected by environmental and genetic factors. Studies of growth pattern and it's understanding not only tell us how plant accumulates dry matter, but also reveals the events which can make a plant more or less productive individually or in population. In a crop the growth parameters like LAI and CGR at flowering have been identified as the major determinants of yield. The combination of these growth parameters explains different yields better than any individual growth variable. Tesfaye *et al*. (2006) [25] reported the attainment of high LAI that reduces soil water evaporation intercepts and converts radiation into dry matter efficiency and partitioning of the dry matter to the seed is the major requirement of a high seed yield in grain legumes in arid environment.

Drought stress and effect of supplemental irrigation studies in mothbean crop growing under agro-climatic conditions of North-western India are meagre. The mothbean crop when supplied with supplemental irrigation before flowering may be beneficial to overcome the harmful effect of drought on the crop and also increases the yield. Besides this, to maintain sustainable crop yield with the added challenge of drought stress, there is an increasing need to exploit existing genetic variability and identify genotypes of mothbean genotypes and their traits, based on growth indices which would facilitate the mothbean crop improvement process for drought stress tolerance (Reynolds *et al*., 2016; Iseki *et al*., 2018) [22, 15]. Therefore, the present study focused on physiological and growth responses of different mothbean genotypes under rainfed and supplemental irrigation conditions.

Materials and Methods

Plant Material and Treatments

Field experiment was conducted during August to October in the year 2020 at the Central Arid Zone Research Institute, Regional Research Station, Bikaner (28°4' N; 74°3' E; 238.3 m above mean sea level), Rajasthan. The climate of the experimental site is hot arid with an average annual precipitation of 287 mm. More than 85% of the total annual rainfall is received during the south west monsoon season (July to September). Total rainfall received during the crop growth period is 91 mm (Table 1). The soil of experimental site was loamy sand, having 8.5 pH, 0.15% organic carbon, 85 kg ha^{-1} available N, 9.6 kg ha^{-1} available P and 256 kg ha^{-1} available K. The seven genotypes of mothbean i.e. RMO-257, RMO-40, RMB-25, RMO-2251, CZM-45 RMO-225 and RMO-435 with two treatments i.e. rainfed (RF) and supplemental irrigation (SI) conditions (One irrigation at 30 days after sowing i.e. before flowering) were laid out in a randomized complete block design with three replications. Size of each plot was 4 m × 2 m with 2 m gap in between. A basal dose of 10 kg N (as urea) and 20 kg P ha^{-1} (As single superphosphate) was applied at sowing. Soil moisture content was measured using soil moisture probe (Profile Probe PR2) at 30, 35, 45 and 50 DAS.

Dry matter accumulation and plant height

Three plants were randomly taken from each plot to determine plant biomass at 35 and 55 DAS. The plants were oven dried at 65 °C ± 5 °C till constant dry weight following which the dry mass was recorded and expressed as g dry wt plant^{-1}. Plant height was measured using scale and is represented in cm.

Determination of Photosynthetic Pigments

Chlorophyll and carotenoid contents were extracted by the non-maceration method (Hiscox and Israelstam, 1979) [12] at 45 DAS. Fresh leaves (0.05 g) were extracted in 10 ml dimethyl sulfoxide (DMSO) for 65 °C for 4 h. The amount of chlorophyll (Chl) *a*, *b* and carotenoids (Car) were determined spectrophotometrically, by reading the absorbance at 645, 663 and 470 nm, respectively. Chl a and Chl b content were calculated according to Arnon (1949) [3] and expressed as mg g^{-1}dw.

Growth indices

Plant growth characteristics i.e. leaf area, LAI, LAD, CGR and NAR were measured by harvesting three plants randomly from each plot at a 10- days interval starting from 35-55 DAS. The total leaf area per plant was measured by portable leaf area meter model (Systronics leaf area meter 211) and expressed as cm^2 plant^{-1}. LAI was calculated by using the formula given by Watson (1947) [27].

LAI = Leaf area/Land area.

LAD was calculated following the protocol devised by Hunt (2012) [13], using the following equation and expressed as days

$$LAD = (LA\ I_1 + LA\ I_2)\ (t_2 - t_1) / 2$$

Where, LAI_1 and LAI_2 are the leaf area index of a plant at time interval t_1 and t_2 (days), respectively.

NAR was calculated based on method given by Williams (1948) [28] and expressed as mg cm^{-2} day^{-1}.

$$NAR = W_2 - W_1 / t_2 - t_1 \times \text{Log}_e\ LA_2 - \text{Log}_e\ LA_1 / LA_2 - LA_1$$

Where, LA_1 and LA_2 are the leaf area (cm^2) and W_1 and W_2 are total dry weight of a plant (mg) at time interval t_1 and t_2 (days), respectively.

CGR was calculated based on the values of LAI and NAR by using following formula and is expressed as mg. cm^{-2}.day^{-1}.

CGR = LAI * NAR

Statistical analysis

Before analysis, the Shapiro Wilk test at 0.05 was conducted using "R v. 4.3.2" in Rstudio 2023.12.0 + 369 to test the normality of the data and fitting data transformation was performed for any data that was not normally distributed. Analysis of variance (ANOVA) was performed and figures were made using the same software.

Results

Soil moisture content

Soil moisture content of the experimental field was measured at 30, 35, 45 and 50 DAS of mothbean genotypes under both RF and SI condition (Fig. 1). Soil moisture was more in SI condition than RF condition at all the stages. Soil moisture continuously decreased in both the RF and SI condition with progression of the stages of crop growth. The decrease in surface water content i.e. at 100 mm is highest as compared to other depths of soil in both RF and SI conditions whereas at 1000 mm depth availability of water is least and is constant throughout the growth stages.

Plant biomass and plant height
Plant biomass and plant height was observed under RF and SI condition at two growth stages i.e. 35 and 55 DAS and is presented in Fig. 2. Biomass across the mothbean genotypes was in general higher under the SI condition than RF condition. SI also increased the plant height significantly across all the genotypes especially at later stages of plant growth i.e. 55 DAS as compared to RF condition (Table S1). The plant height and biomass showed a growth-related increase from 35 to 55 DAS i.e. from vegetative to maturity stage across all the genotypes.

Photosynthetic pigments (Chl a, Chl b, Chla/b ratio and Chl/car ratio)
SI condition brought significant improvement in Chl a and Chl b content while Chl a/b ratio and Chl/car ratio was at par in all the mothbean genotypes (Fig. 3, Table S1). RMO-40 variety showed highest content of Chl a and Chl b while chl a/b and Chl/Car ratio were recorded maximum in CZM-45 under SI condition. However, the highest content of Chl a and Chl b were recorded with RMO-225 variety under RF condition. Chl a/b ratio and Chl/Car ratio didn't show any significant differences among the genotypes under both RF and SI condition (Table S1).

Growth indices (Leaf area, LAI, LAD, NAR and CGR)
Leaf area of mothbean genotypes were shown at two stages of growth i.e. 35 and 55 DAS under RF and SI condition in Fig. 4. Leaf area of mothbean genotypes showed significant increase with growth period and more area was observed in SI condition as compared to RF condition. Water availability improves two to three times of the leaf area in mothbean genotypes with highest effect at later stages of plant growth. The observations for LAI, LAD, NAR and CGR were taken at different interval i.e. 35-45, 45-55 and 35-55 DAS. SI condition significantly increased LAI at all the stages and percent increase under SI condition as compared to RF condition was higher at later stages of plant growth (Table 2). Values for LAI were non-significant across the genotypes under RF and SI conditions. Very similar results to LAI were observed for LAD parameter (Table 2). Difference between the genotypes for LAD was not significant under both RF and SI condition at all the stages of plant growth. NAR showed significant increase with increasing the plant growth stages and at initial stages of plant growth it was recorded highest under SI condition as compared to RF condition in all the genotypes. RMO-40 and RMO-257 genotypes was showing highest values for NAR in SI and RF conditions respectively as compared to other genotypes especially at later stages of plant growth (Table 3). CGR represents the gain in dry matter production per unit area per unit time and was observed higher under SI condition as compared to RF condition in all the mothbean genotypes at all stages of growth. RMO-40 and RMO-2251 genotypes were showing more CGR values at later stages of plant growth as compared to other genotypes (Table 3).

Discussion
Drought is a major abiotic stress which adversely affects plant growth and development. Climate change has worsened drought in drier areas due to increase in temperature and erratic rainfall patterns (Overpeck and Udall, 2020) [21]. Drought leads to reduction in biomass production which results in quantitative and qualitative yield losses, especially in rainfed agriculture system (Kumar and Chander, 2020) [18]. Rainfed agriculture system is mainly adopted in mothbean cultivation in arid regions of Rajasthan which is highly affected by the unpredictable and less rainfall in the region. This condition leads to drought stress in mothbean cultivation and if it coincides with reproductive stage results in maximum percent reduction in yield. Therefore, optimum irrigation facilities and selection of drought tolerant mothbean genotypes may be beneficial strategy for achieving potential yield under changing climatic conditions. Seven mothbean genotypes were evaluated under RF and SI conditions to determine their growth responses to SI condition. Soil moisture content under RF condition showed continuous decrease with crop growth stages due to less rainfall during the crop growth period. This decrease in soil moisture level resulted in drought conditions under RF irrigation therefore the SI may be a requisite for mothbean cultivation under such areas to maintain the soil moisture and for increasing productivity (Fabeiro *et al*., 2001; Du *et al*., 2010) [7, 5]. The importance of irrigation under RF cultivation in these changing climatic conditions was also suggested by Elliott *et al.* (2014) [6]. Higher dry matter accumulation under SI condition is due to higher leaf area which results in higher light interception and higher net photosynthesis. Vieira *et al*. (1991) [26] stated the main reason of reduction in dry weight and plant height in water stress is due to reduction in photosynthesis. Similarly, the decrease in total chlorophyll content under water stress condition is attributed to lower photosynthetic rate due to stomatal closure and deformation of plastids and protein membranes of thyllakoids thus reduction in electron transfer (Yang *et al*., 2001; Kannan and Kulandaivelu, 2011) [29, 16]. Similar decrease in chlorophyll and carotenoid content was also observed in mothbean under drought condition by Garg *et al*. (2001) [10]. An increase in Chl a/b ratio was observed under RF condition in almost all the genotypes. The increase in chl a/b ratio under stress condition were also reported and well discussed in other crops (Nahakpam, 2017; Guo *et al*., 2016) [19, 11]. It was observed that the RF conditions negatively affected growth parameters i.e. leaf area, LAI, LAD, CGR and NAR of mothbean genotypes. SI proved to be significant for increasing leaf area at all the stages of crop growth. Leaf area reduction is a mechanism adopted by the plants for minimizing transpiration to tolerate drought conditions. Water limiting conditions caused reduction in leaf area due to inhibition of cell expansion by declining rate of cell division and loss of cell turgidity (Bangar *et al*., 2019) [4]. LAI and LAD are also associated with leaf area thus reduced under RF condition and significantly improved under SI condition. Compared to the RF condition, SI condition resulted in gradual increase in CGR and NAR in all the mothbean genotypes. This increase in CGR and NAR is due to increase in leaf area and LAI which increased the net photosynthetic rate and lead to overall growth of the plant. Sharifi and Raei (2011) [23] also reported that higher LAI increases the absorption of solar energy and biomass production which may contribute to increase in NAR and CGR. Hussein *et al*. (2011) [14] also showed significant decrease in LAI and LAD in beet plants under RF condition due to decrease in leaf area. RMO-257 showed higher values for leaf area, LAI and LAD under RF condition which shows that these genotypes are more tolerant to drought stress conditions as compared to other genotypes. RMO-435 was showing lowest values for leaf area, LAI and LAD under RF conditions and SI significantly improved the leaf area, LAI and LAD, thus this genotype is drought susceptible and requires SI for better growth and development. Similar results were also observed for CGR and NAR in these genotypes.

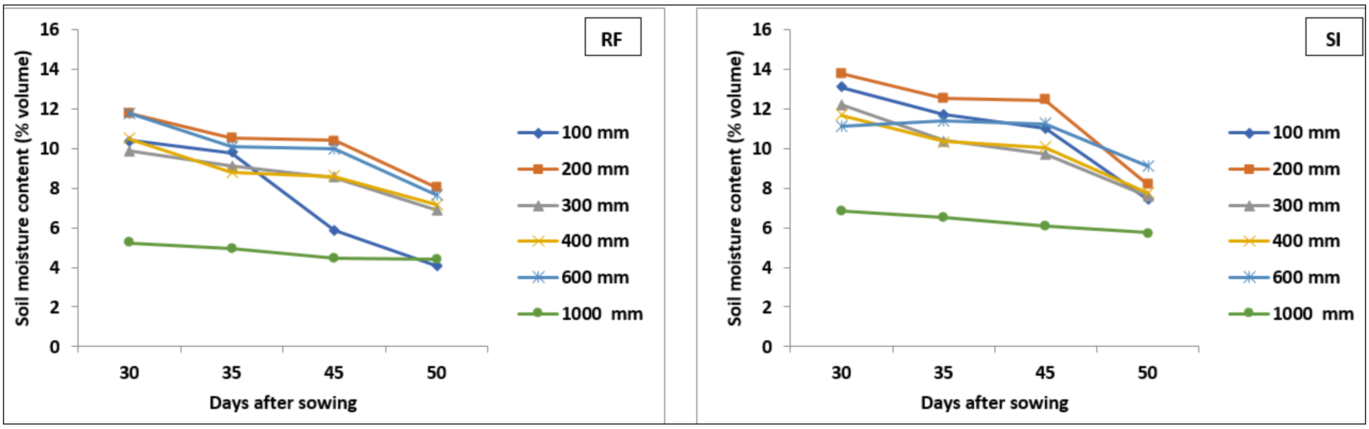

Fig 1: Soil moisture content (% volume) at different days after sowing of mothbean genotypes under rainfed (RF) and supplemental irrigation (SI) condition

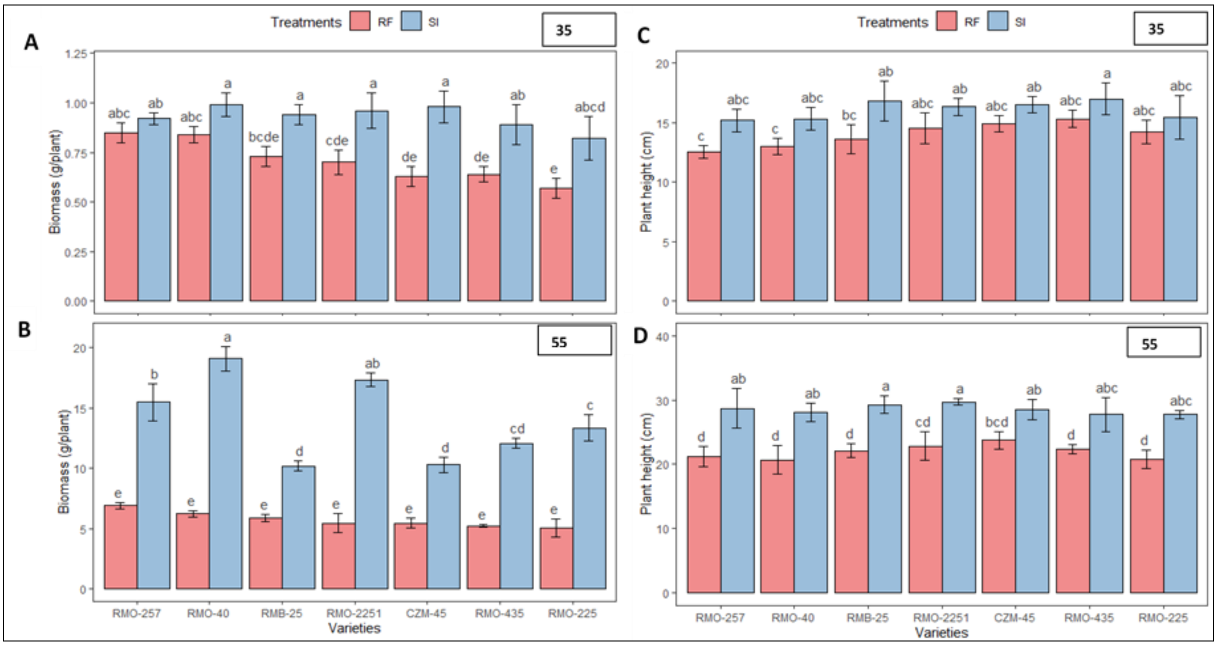

Fig 2: Plant biomass (A and B) and plant height (C and D) of seven mothbean genotypes at 35 and 55 days after sowing (DAS) grown under rainfed (RF) and supplemental irrigation (SI) condition. Presented values are mean ± SD (n=3). Data bar with different alphabet, within a genotype, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple range test

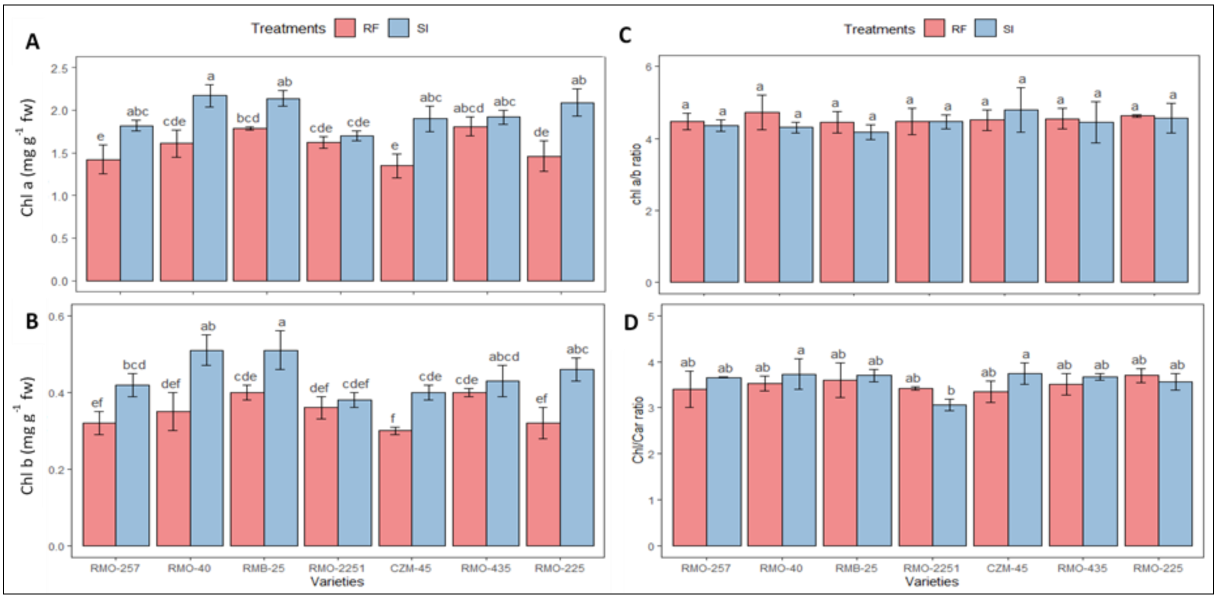

Fig 3: Chlorophyll (Chl) a (A), Chl b (B) content, Chl a/b ratio (C) and chl to carotenoid (Car) ratio (D) of seven mothbean genotypes at 45 days after sowing (DAS) grown under rainfed (RF) and supplemental irrigation (SI) condition. Presented values are mean ± SD (n=3). Data bar with different alphabet, within a genotype, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple range test

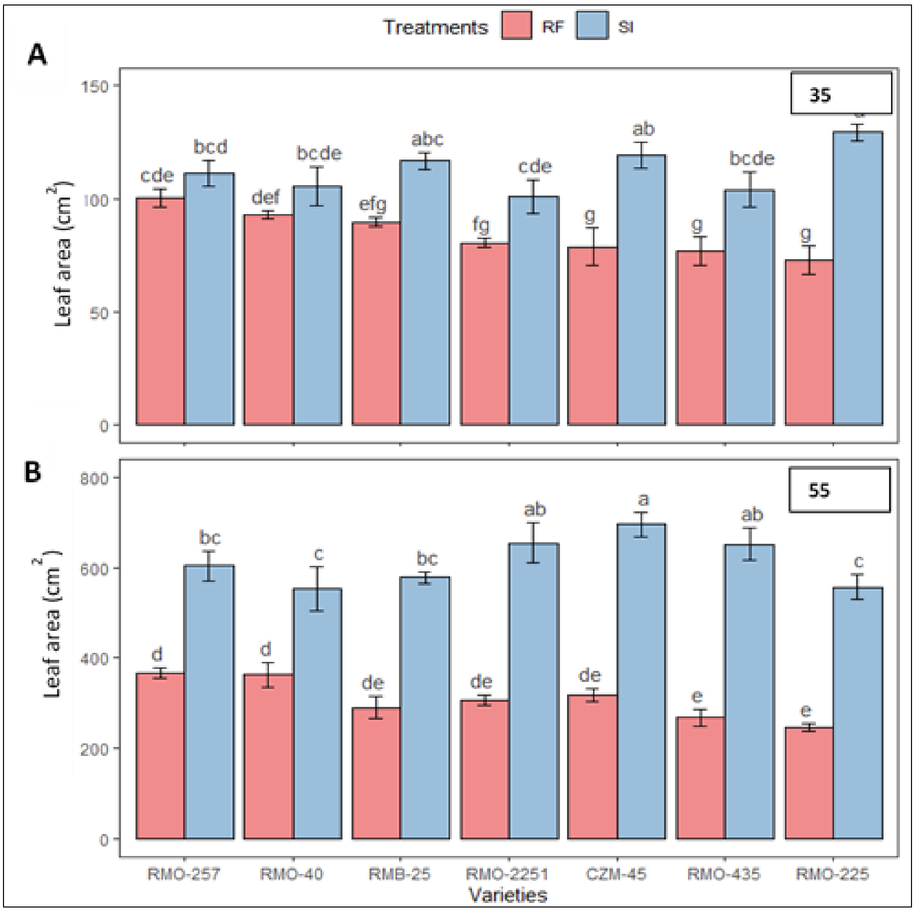

Fig 4: Leaf area of seven mothbean genotypes at 35 (A) and 55 (B) days after sowing (DAS) grown under rainfed (RF) and supplemental irrigation (SI) condition. Presented values are mean ± SD (n=3). Data bar with different alphabet, within a genotype, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple range test

Table 1: Weather data for the growing period of mothbean at the CAZRI (RRS), Bikaner

Months	Relative Humidity (%)	Average Temperature (°C)	Evaporation (mm)	Total Rainfall (mm)
August	56.31	32.27	10.82	99.2
September	50.45	31.89	11.33	16.4
October	44.56	27.17	9.27	0.0

Source: Meteorological station, CAZRI (RRS), Bikaner

Table 2: Leaf area index and leaf area duration of seven mothbean genotypes under rainfed (RF) and supplemental irrigation (SI) condition

Genotypes	Treatments	Leaf area index			Leaf area duration (days)		
		Days after sowing (DAS)					
		(35-45 DAS)	(45-55 DAS)	(35-55 DAS)	(35-45 DAS)	(45-55 DAS)	(35-55 DAS)
RMO-257	RF	0.25de	0.63ef	0.92d	4.42d	7.75e	11.67e
	SI	0.28bc	1.05d	1.51b	6.64c	12.80cd	17.87bc
RMO-40	RF	0.23ef	0.66e	0.91de	4.44d	7.81e	11.39e
	SI	0.26cd	1.33a	1.38c	7.96a	13.54bc	16.44d
RMB-25	RF	0.22fg	0.55ghi	0.73fg	3.88ef	6.38fg	9.50fg
	SI	0.29b	1.08d	1.44bc	6.86c	12.62d	17.35cd
RMO-2251	RF	0.20gh	0.59efg	0.77f	3.98e	6.81f	9.70fg
	SI	0.25cde	1.22bc	1.63a	7.36b	14.27ab	18.87b
CZM-45	RF	0.20h	0.58fgh	0.79ef	3.87ef	6.85f	9.90f
	SI	0.30b	1.18bc	1.74a	7.38b	14.59a	20.37a
RM0-435	RF	0.19h	0.52hi	0.67fg	3.56fg	5.96g	8.64gh
	SI	0.26cd	1.23b	1.63a	7.47b	14.31ab	18.88b
RMO-225	RF	0.32a	0.49i	0.62g	3.37g	5.55g	8.01h
	SI	0.18h	1.15c	1.39bc	7.38b	12.73cd	17.16cd
Variation source	df	Mean square					
Treatments (T)	1	0.051 (***)	3.812 (***)	6.085 (***)	118.64 (***)	488.3 (***)	724.7 (***)
Genotypes (G)	6	0.001 (***)	0.022 (***)	0.045 (***)	0.48 (***)	2.2 (***)	4.3(***)
T * G	6	0.002 (***)	0.015 (***)	0.049 (***)	0.55 (***)	2.1 (***)	6.3 (***)
Error	28	0.000	0.002	0.005	0.04	0.2	0.5

Data with different alphabet, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple comparison tests for post hoc analysis, "***" and "**" are significance codes at 0.001 and 0.001, respectively and "ns" is not significant

Table 3: Crop growth rate and net assimilation rate of seven mothbean genotypes under rainfed (RF) and supplemental irrigation (SI) condition

Genotypes	Treatments	Crop growth rate (mg cm^{-2} day^{-1})			Net assimilation rate (mg cm^{-2} day^{-1})		
		Days after sowing (DAS)					
		(35-45 DAS)	(45-55 DAS)	(35-55 DAS)	(35-45 DAS)	(45-55 DAS)	(35-55 DAS)
RMO-257	RF	0.52cd	5.37e	26.96e	2.09cd	8.48ef	29.42e
	SI	0.74a	17.40c	75.58b	2.65a	16.58bc	49.98b
RMO-40	RF	0.44de	4.95e	24.66ef	1.87def	7.54f	27.22e
	SI	0.68ab	27.88a	92.42a	2.57ab	21.05a	67.35a
RMB-25	RF	0.36ef	5.97e	21.64ef	1.63efg	10.84def	30.03e
	SI	0.67ab	8.01e	46.37d	2.30abc	7.41f	32.13de
RMO-2251	RF	0.33ef	5.28e	21.49ef	1.64efg	8.82ef	28.10e
	SI	0.59bc	22.90b	90.49a	2.34abc	18.76ab	55.41b
CZM-45	RF	0.27f	6.09e	22.27ef	1.37g	10.59def	28.18e
	SI	0.60bc	8.53e	49.48d	2.01cde	7.25f	28.50e
RM0-435	RF	0.29f	5.69e	20.06ef	1.51fg	10.93def	29.91e
	SI	0.59bc	11.95d	61.04c	2.26abcd	9.68def	37.46cd
RMO-225	RF	0.25f	6.05e	19.42f	1.38g	12.49de	31.35de
	SI	0.70ab	15.59c	59.42c	2.17bcd	13.55cd	42.77c
Variation source	df	Mean square					
Treatments (T)	1	4.978 (***)	129.68 (***)	2564.6 (***)	0.9390 (***)	1138.2 (***)	21714 (***)
Genotypes (G)	6	0.344 (***)	29.80 (***)	256.7 (***)	0.0304 (***)	73.3 (***)	598 (***)
T * G	6	0.008 (ns)	429.2 (***)	315.2 (***)	0.0085 (ns)	90.7 (***)	468 (***)
Error	28	0.050	5.34	13.2	0.0040	3.7	15

Data with different alphabet, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple comparison tests for post hoc analysis, "***" and "**" are significance codes at 0.001 and 0.001, respectively and "ns" is not significant

Conclusion
Insufficient rainfall during critical growth stages in mothbean crop limits the production and productivity under RF ecosystems. The present study showed that the SI significantly increased plant biomass, photosynthetic pigments, and growth traits such as LAI, LAD, NAR and CGR in mothbean genotypes as compared to the RF condition. However, among different mothbean genotypes, RMO-257 was performing better under RF condition which shows that it has maximum capacity to tolerate drought stress condition as compared to other genotypes. Therefore, SI at 30 DAS i.e. before the onset of flowering and selection of drought tolerant genotype i.e. RMO-257 are recommended for obtaining higher growth rates and ultimately yield in mothbean in arid and semiarid regions of Rajasthan.

Acknowledgements
Authors thank ICAR-CAZRI (RRS), Bikaner and ICAR-NRCSS, Ajmer for providing funds and facilities for conducting this study.

Authors contributions
VS performed the experimental work and wrote the draft manuscript, NSN supervised the research and finalized the manuscript and SNS helped with physiological and growth studies.

Competing interests' declaration
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.

References
1. Ahluwalia O, Singh PC, Bhatia R. A review on drought stress in plants: Implications, mitigation and the role of plant growth promoting rhizobacteria. Resources, Environment and Sustainability. 2021;5:100032.
2. Anjum SA, Wang LC, Farooq M, Hussain M, Xue LL, Zou CM. Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. Journal of Agronomy and Crop Science. 2011;197(3):177-185.
3. Arnon DI. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vulgaris. Plant Physiology. 1949;24(1):1.
4. Bangar P, Chaudhury A, Tiwari B, Kumar S, Kumari R, Bhat KV. Morphophysiological and biochemical response of mungbean [*Vigna radiata* (L.) Wilczek] varieties at different developmental stages under drought stress. Turkish Journal of Biology. 2019;43(1):58-69.
5. Du T, Kang S, Sun J, Zhang X, Zhang J. An improved water use efficiency of cereals under temporal and spatial deficit irrigation in north China. Agricultural Water Management. 2010;97(1): 66-74.
6. Elliott J, Deryng D, Müller C, Frieler K, Konzmann M, Gerten D, *et al*. Constraints and potentials of future irrigation water availability on agricultural production under climate change. Proceedings of the National Academy of Sciences. 2014;111(9):3239-3244.
7. Fabeiro CM, de Santa Olalla FM, De Juan JA. Yield and size of deficit irrigated potatoes. Agricultural Water Management. 2001;48(3):255-266.
8. Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, *et al*. Crop production under drought and heat stress: plant responses and management options. Frontiers in Plant Science; c2017. p. 1147.
9. Garg BK, Burman U. Moth bean Physiology, In D. Kumar and N.B. Singh: Moth bean in India. Scientific Publishers, Jodhpur; c2002. p. 87-102.
10. Garg BK, Kathju S, Burman U. Influence of water stress on water relations, photosynthetic parameters and nitrogen metabolism of moth bean genotypes. Biologia Plantarum. 2001;44:289-292.
11. Guo YY, Yu HY, Kong DS, Yan F, Zhang YJ. Effects of drought stress on growth and chlorophyll fluorescence of *Lycium ruthenicum* Murr. seedlings. Photosynthetica. 2016;54(4):524-531.
12. Hiscox JD, Israelstam GF. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian

journal of botany. 1979;57(12):1332-1334.
13. Hunt R. Basic growth analysis: plant growth analysis for beginners. Springer Science and Business Media, Berlin; c2012.
14. Hussein MM, Shaaban MM, El-Saady AM, El-Sayed AA. Growth and photosynthetic pigments of fodder beet plants as affected by water regime and boron foliar fertilization. Nature and Science. 2011;9(1):72-79.
15. Iseki K, Takahashi Y, Muto C, Naito K, Tomooka N. Diversity of drought tolerance in the genus Vigna. Frontiers in Plant Science. 2018;9:729.
16. Kannan ND, Kulandaivelu G. Drought induced changes in physiological, biochemical and phytochemical properties of Withania somnifera Dun. Journal of Medicinal Plants Research. 2011;5(16):3929-3935.
17. Kukal SS, Jat ML, Sidhu HS. Improving water productivity of wheat-based cropping systems in South Asia for sustained productivity. Advances in Agronomy. 2014;127:157-258.
18. Kumar G, Chander H. Socio-economic impacts of drought tolerant and pest resistant cultivars of wheat to marginal landholders of rainfed Hamirpur region in Himachal Pradesh, India. Journal of Interdisciplinary Cycle Research. 2020;12(8):2018-2036.
19. Nahakpam S. Chlorophyll stability: a better trait for grain yield in rice under drought. Indian Journal of Ecology. 2017;44(4):77-82.
20. Okada M, Iizumi T, Sakamoto T, Kotoku M, Sakurai G, Hijioka Y, *et al*. Varying benefits of irrigation expansion for crop production under a changing climate and competitive water use among crops. Earth's Future. 2018;6(9):1207-1220.
21. Overpeck JT, Udall B. Climate change and the aridification of North America. Proceedings of the national academy of sciences. 2020;117(22):11856-11858.
22. Reynolds M, Langridge P. Physiological breeding. Current Opinion in Plant Biology. 2016;31:162-171.
23. Sharifi RS, Raei Y. Evaluation of yield and the some of physiological indices of barley (*Hordeum vulgari* L.) genotypes in relation to different plant population levels. Australian Journal of Basic and Applied Sciences. 2011;5(9):578-584.
24. Sharma BR, Rao KV, Vittal KP, Ramakrishna YS, Amarasinghe U. Estimating the potential of rainfed agriculture in India: Prospects for water productivity improvements. Agricultural Water Management. 2010;97(1):23-30.
25. Tesfaye K, Walker S, Tsubo M. Radiation interception and radiation use efficiency of three grain legumes under water deficit conditions in a semi-arid environment. European journal of Agronomy. 2006;25(1):60-70.
26. Viera HJ, Bergamaschi H, Angelocci LR, Libardi PL. Performance of two bean cultivars under two water availability regimes. II. Stomatal resistance to vapour diffusion, transpiration flux density and water potential in the plant. Pesquisa Agropecuaria Brasileira. 1991;24(9):1045-1053.
27. Watson DJ. Comparative physiological studies on the growth of field crops: I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. Annals of Botany. 1947;11(41):41-76.
28. Williams RF. The physiology of plant growth with special reference to the concept of net assimilation rate. Annals of Botany. 1946;10(37):41-72.
29. Yang J, Zhang J, Wang Z, Zhu Q, Liu L. Water deficit–induced senescence and its relationship to the remobilization of pre-stored carbon in wheat during grain filling. Agronomy Journal. 2001;93(1):196-206.

Table S1: Mean squares and degree of freedom of mothbean plants

Variation source	df	Biomass		Plant height		Leaf area	
		Days after sowing (DAS)					
		35	**45**	**35**	**45**	**35**	**45**
Treatments (T)	1	0.515 (***)	712.8 (***)	45.26 (***)	456.7 (***)	7787 (***)	973349 (***)
Genotypes (G)	6	0.187 (***)	21.3 (***)	4.07 (*)	4.0 (ns)	215 (***)	7223 (***)
T * G	6	0.076 (*)	15.8 (***)	0.72 (ns)	1.6 (ns)	421 (***)	7849 (***)
Error	28	0.004	0.5	1.21	3.0	33	759

Variation source	df	Chlorophyll a	Chlorophyll b	Chlorophyll a/b ratio	Chlorophyll/ Carotenoid ratio
		45 Days after sowing (DAS)			
Treatments (T)	1	1.52 (***)	0.093 (***)	0.102 (ns)	0.084 (ns)
Genotypes (G)	6	0.12 (***)	0.009 (***)	0.072 (ns)	0.121 (*)
T * G	6	0.07 (**)	0.004 (**)	0.070 (ns)	0.098 (ns)
Error	28	0.02	0.001	0.15	0.048

“***“, and “**” are significance codes at 0.001 and 0.001, respectively and “ns” is not significant