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Oil yield and profitability of Indian mustard (*Brassica juncea* L) as influenced by superabsorbent polymer, plant bio-regulators and soil moisture regimes

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Abstract

A field experiment was conducted during *Rabi* season of 2018-19 to evaluate the field efficacy of superabsorbent polymer (SAP: Pusa hydrogel) and plant bio-regulators (PBR's) on growth, yield attributes, oil yield and economics of Indian mustard. PBR's like salicylic acid (SA, 100 ppm), thiourea (TU, 0.1%) and potassium nitrate (PN, 1.5%) along with SAP (2.5 kg/ha) were compared with control under moisture stress and normal moisture regimes in a factorial randomized complete block design with three replications. Results revealed that dry matter accumulation per plant, leaf chlorophyll content (SPAD), siliquae weight per plant, seed weight per plant, 1000-seed weight and oil content were decreased on an average by 8.3, 9.1, 10.4, 12.7, 7.7 and 0.7 %, respectively due to moisture stress imposed during post flowering period as compared to normal moisture regime. Further, moisture stress significantly declined the oil yield by 11.8 % and net returns by 13.1 % over the normal moisture regime. Nevertheless, these growth, yield and profitability parameters under both the moisture regimes were improved substantially with the combined application of SAP+PBR's, though greater response was observed under moisture stress regime. SAP+SA, being on par with SAP+TU and SAP+PN resulted the maximum oil yield (1.10 t/ha) and net returns (75.15×10^3 Rs./ha) which was found significantly higher by 8.8 and 12.2 % over the SAP and by 30.3 and 34.0% over the control, respectively. The maximum B:C ratio was recorded with SAP+SA which was observed significantly higher over the rest of the treatments. Thus, combined application of SAP and PBRs (especially SA) can be recommended to mitigate deficit moisture stress, saving of irrigation water and to enhance the oil yield and profitability of Indian mustard in drought prone/ rainfed areas.

Keywords: *Economics, Indian mustard, moisture stress,oil yield, plant bio-regulators, superabsorbent polymer*

Introduction

Indian mustard [*Brassica juncea* (L.) Czern & Coss] is an economically important oilseed crop of the Brassicaceae family, grown in winter season (*Rabi*) mainly in northern, north-western and western India. It was cultivated on 8.06 million hectares of area with 11.75 million tonnes production and 1458 kg/ha productivity in India during 2021-22. Rajasthan being the leading state in India occupied 3.37 million hectares area (41.8 %) and 5.48 million tonnes (46.6 %) of mustard with average productivity of 1627 kg/ha during 2021-22 (Anonymous, 2022). India had imported 14.19 million tonnes of edible oil to meet out its domestic requirements (25.77 million tonnes) of growing population during 2021-22 (Anonymous, 2022). Moreover, average mustard productivity in India is also far behind than the world because of large scale cultivation under rainfed conditions where crop often encounter biotic and abiotic stresses, and resources crunch (Jat *et al.,* 2021; Jat *et al.,* 2019). Drought is one of the most important limiting factors for mustard growth and productivity, especially during the reproductive stages, which can reduce seed yield (Choudhary *et al.,* 2021; Rathore *et al.,* 2019). Moisture stress during growing season in rapeseed-mustard could reduce the production by 17 to 94 % (Chauhan *et al.,* 2011). Further, moisture stress at post flowering stages of the crop has led to a drastic decline in growth and yields of Indian mustard (Choudhary *et al.,* 2023; Langadi *et al.,* 2021). Thus, strategies like enhancing the moisture supply in the root zone and improving the drought tolerance ability of the crop could be helpful in mitigating the moisture stress and enhancing the productivity and profitability of the crop under drought like situations.

Superabsorbent polymers (SAPs) like hydrogel are promising option to exploit the existing water use in soil for the field and horticultural crops (Kalhapure *et al.,* 2016; Tian *et al.,* 2019). Many researchers have reported that use of SAP improves the soil moisture conservation and thereby moisture stress mitigation in several crops including the mustard (Choudhary *et al.,* 2023 & 2021; Rathore *et al.,* 2019). The applications of plant bio-regulators (PBRs) are found to play an important role in plant responses to water stress (Choudhary *et al.,* 2023; Shah *et al.,* 2021; Wakchaure *et al.,* 2016a; Wakchaure *et al.,* 2016b). Plant hormone like salicylic acid is one of the strong candidates for stress ameliorators which plays a pivotal role in regulating numerous plant morpho-physiological and biochemical processes in crops including edible oilseed crop plants (Pluharova *et al.,* 2019; Shaki *et al.,* 2020). Thiourea is an another PBR which helps to improve phloem translocation of photosynthate in crop plants and thereby, induces drought and salinity tolerance in cereals, pulses, oilseeds and spices (Bhunia *et al.,* 2015). Potassium nitrate can help to alleviate abiotic stress by increasing photosynthate translocation and enhancing gas exchange, protein synthesis, enzyme activity, and stomatal conductance (Zahoor *et al.,* 2017). Therefore, we studied the effect of SAP and different PBR's on the growth, yield attributes, oil content and yield and economics of Indian mustard under different moisture regimes.

Materials and Methods

Soil and climate

The present field experiment was executed during *Rabi* season of 2018-19 at the research farm of ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan (27°12'8.9" N latitude, 77°27'18.8" E longitude and 178.4 m above MSL altitude). Before start of the experiment, soil samples (0-15 cm depth) were collected and analyzed to determine the soil physical and chemical properties. The experimental soil at site was clay loam in texture and it had 0.41 % organic carbon, 225.1 kg/ha $KMnO_4$ oxidizable nitrogen, 20.1 kg/ha 0.5 N $NaHCO_3$ extractable phosphorus, 172.4 kg/ha 1.0 N NH_4OAc exchangeable potassium, 8.2 pH and 0.72 dS/m electrical conductivity. Hot dry summer, cold winter and short monsoon periods are the climatic chrematistics of the Bharatpur region. This region receives on an average 650 mm annual rainfall of which 85 % is contributed by south-west monsoon during June to September. A total 37.4 mm rainfall was received during the crop growing period of 2018-19. The daily values of the maximum and minimum temperature, maximum and minimum relative humidity, bright sunshine hours and wind velocity during the crop growing period were ranged between 15-34.8 °C, 0.4-21.8°C, 70.5-97.3 %, 45.3-89.4 %, 0-10 hours/day and 0-7.6 km/hr, respectively.

Treatment details and crop management practices

Field experiment was carried out in a factorial randomized block design and with three replications. There were twelve treatment combinations consisting two moisture regimes (normal moisture and moisture stress) and six treatment of moisture stress mitigation options which included three plant bio-regulators [(PBR's; salicylic acid, SA (100 ppm); thiourea, TU (0.1%); potassium nitrate, PN (1.5%)] along with a superabsorbent polymer-*Jal Nidhi Pusa hydrogel* (SAP, 2.5 kg/ha), SAP alone (2.5 kg/ha), water-treated control and control (without PBR, SAP and water). As per the treatments, SAP was placed in the root zone at sowing time of the crop. The PBR's were sprayed at flower initiation and siliqua formation stages of the mustard. One irrigation (34 days after sowing, DAS) under moisture stress and two irrigations (34 and 70 DAS) under normal moisture regimes were applied to the mustard. The 2^{nd} irrigation was escaped under the moisture stress regime. Crop (var. DRMRIJ 31) was sown on 18 October 2018 with a seed drill using 4 kg seeds/ha. Gap filling, thinning and interculture operations were done and a planting geometry of 45 cm × 10-15 cm was kept to maintain the optimum plant population. The recommended dose of fertilizers viz., 80:40:40:40:5:1 kg/ha of $N:P_2O_5:K_2O:S:Zn:B$ were uniformly applied to all the treatments through urea, single super phosphate, muriate of potash, zinc sulphate and borax fertilizers. The 100 % dose of all nutrients, except N was applied as basal at the time of sowing, while 50 % N applied as basal and 50 % N was top dressed after first irrigation. One hand weeding with a hand hoe was done during 25-30 DAS to remove the weeds from the experimental plots. Other recommended crop management practices were followed to harvest a good crop.

Observations

Randomly selected five plants were collected at maturity of the crop to record the observations on dry matter accumulation, siliqua weight per plant, seed weight per plant and 1000-seed weight. The leaf chlorophyll content in terms of SPAD chlorophyll meter readings (SCMR) values which represent the chlorophyll or relative N content in intact mustard leaves were measured at 45 and 75 DAS using a SPAD 502 Chlorophyll Meter. The oil content in the seed was determined with near infrared reflectance spectroscopy (NIRS, Model FOSS 6500) by using non-destructive method of oil estimation as suggested by Alexander *et al.* (1967) using equation developed for mustard samples. Accordingly, the oil yield was calculated by multiplying the oil content in the seed sample of each treatment with its respective seed yield and expressed in t/ha.

Economics

The economics of cultivation was worked out on the basis of prevailing market price of produce and cost of inputs. Net returns were estimated by deducting the total cost of cultivation from gross returns, and benefit: cost (B:C) ratio was calculated by dividing net returns with total of fixed and variable costs. Price of per kilogram seed, stover, SAP, SA, TU and PN were Rs. 42, 1.0, 1168, 2220, 3230 and 190 during 2018-19. The ratio of net returns and crop growing period was expressed in terms of economic efficiency.

Statistical analysis

The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique for a factorial randomized block design using SAS package (*ver.* 9.3). The results have been presented at 5 % level of significance ($p \leq 0.05$). Correlation matrix between the seed yield and yield attributes of mustard was determined by using the data analysis tool of MS-excel 2019.

Results and Discussion

Plant growth and yield attributes

A significant effect of different soil moisture regimes and moisture stress mitigation options on most of the growth and yield attributes *viz.,* dry matter accumulation (DMA) per plant, siliquae weight, seed weight per plant, 1000-seed weight and oil content in seed of Indian mustard was observed (Table 1). The DMA per plant, siliquae weight per plant, seed weight per plant, 1000-seed weight and oil content were decreased on an average by 8.3, 10.4, 12.7, 7.7 and 0.7 %, respectively due to moisture stress as compared to normal moisture regime (Table 1), though, decrease in oil content was not observed significant. However, combined application of PBRs (SA/TU/PN) and SAP improved these growth and yield parameters substantially particularly under the moisture stress regime (Table 1). SAP+SA, being on par with SAP+TU/PN resulted the maximum values of these growth and yield parameters which was found significantly higher over the SAP, water spray and control treatments. Further, DMA, siliquae weight per plant, seed weight per plant, 1000-seed weight and oil content in seed improved with the application of SAP + PBRs on an average by 12.5-17.8, 7.3-9.2, 12.0-14.9, 7.9-9.0 and 4.0-4.5 %, respectively over the control. The higher values of DMA and yield attributes under normal moisture regime over the moisture stress regime, and SAP+PBRs (particularly with SA) over the control treatments might be due to improved water supply (irrigation and SAP) and mitigation of water stress (PBRs) which provided a congenial growth environment for cell elongation, cell turgidity, opening of stomata and finally the partitioning of photosynthates efficiently to the sink (Choudhary *et al.,* 2023; Choudhary *et al.,* 2020; Singh *et al.,* 2018; Yadav *et al.,* 2010). Choudhary *et al.* (2021) also reported that application of SAP to Indian mustard helps in maintaining the optimal moisture regime in soil and significantly improved the number of branches per plant, number of siliquae and seeds per siliqua. Further, PBRs also mediates the response of plants and provide the drought tolerance under moisture stress conditions (Shah *et al.,* 2021; Pluharova *et al.,* 2019). Choudhary *et al.* (2023) reported that spraying of PBRs (salicylic acid > thiourea > potassium nitrate) on mustard at flower initiation and siliqua formation stages significantly enhanced its number of branches, main shoot length, number of siliquae, siliqua length and seeds per siliqua over the control.

Table 1: Effect of soil moisture regimes and moisture stress mitigation options on growth and yield attributes of Indian mustard

Soil moisture regimes	Moisture stress mitigation options						Mean
	SAP	SAP+TU	SA P+PN	SAP+SA	Water	Control	
Dry matter (g/plant)							
Normal moisture	104	112	110	116	101	104	108
Moisture stress	100	103	106	110	87	88	99
Mean	102	108	108	113	94	96	
	A. Soil moisture regimes			B. Moisture stress mitigation options			A × B
SEm ±	1.5			2.5			3.6
LSD ($p \leq 0.05$)	4.3			7.4			NS
Siliquae weight (g/plant)							
Normal moisture	61.8	63.4	64.1	64.2	61.4	61.7	62.8
Moisture stress	57.2	58.2	58.0	59.7	52.9	51.6	56.3
Mean	59.5	60.8	61.0	61.9	57.2	56.7	
	A. Soil moisture regimes			B. Moisture stress mitigation options			A × B
SEm ±	0.74			1.28			1.81
LSD ($p \leq 0.05$)	2.17			3.76			NS

Seed weight (g/plant)							
Normal moisture	39.4	40.8	41.4	41.6	38.5	38.4	40.0
Moisture stress	33.5	37.2	37.0	38.4	32.4	31.3	35.0
Mean	36.4	39.0	39.2	40.0	35.5	34.9	
	A. Soil moisture regimes			B. Moisture stress mitigation options			A × B
SEm ±		0.75			1.31		1.85
LSD ($p \leq 0.05$)		2.21			3.83		NS
1000-seed weight (g)							
Normal moisture	6.05	6.29	6.26	6.31	5.87	5.79	6.10
Moisture stress	5.62	5.84	5.77	5.85	5.34	5.38	5.63
Mean	5.83	6.07	6.02	6.08	5.60	5.58	
	A. Soil moisture regimes			B. Moisture stress mitigation options			A × B
SEm ±		0.07			0.11		0.16
LSD ($p \leq 0.05$)		0.19			0.33		NS
Oil content (%)							
Normal moisture	41.7	41.9	41.5	41.7	42.0	40.3	41.5
Moisture stress	41.8	41.2	41.7	41.8	41.2	39.6	41.2
Mean	41.7	41.6	41.6	41.8	41.6	40.0	
	A. Soil moisture regimes			B. Moisture stress mitigation options			A × B
SEm ±		0.14			0.24		0.34
LSD ($p \leq 0.05$)		NS			0.71		NS

The SCMR which indicates the chlorophyll or relative N content in leaves and over all crop health of the crop varied significantly at 75 DAS due to different soil moisture regimes and moisture stress mitigation options, though it did not differ statistically at 45 DAS (Fig. 1). Among different soil moisture regimes, SCMR values at 75 DAS were recorded 10.1 % higher under normal moisture over the moisture stress regime. The non-significant variation in SCMR under different treatments at 45 DAS was due to uniform supply of soil moisture through application of an irrigation at 35 DAS. But, deficit moisture supply during the post flowering period might have exposed the crop to relatively more water stress which led to decline in SCMR at 75 DAS under the moisture stress regime. Among different moisture stress mitigation options, the maximum SCMR (47.3) was recorded with SAP+SA which was found on par with SAP+TU and SAP+PN but significantly higher by 6.5-17.4 % over rest of the treatments. The limited supply of water and thereby nutrients might have resulted in lower SCMR under the moisture stress. Langadi *et al.* (2021) also reported that application of SAP (2.5-5.0 kg/ha) significantly improved the SCMR over the control and 1.5 kg SAP/ha. Similarly higher SCMR values under normal moisture condition as compared to the moisture stress conditions were also reported by Langadi *et al.* (2021) and Jat *et al.* (2020).

Oil yield

The oil yield (1.06 t/ha) was recorded on an average 13.4 % higher under normal moisture regime over the moisture stress regime (Fig. 2). Langadi *et al.* (2021) also reported a higher oil yield (21.11 %) under normal moisture condition over the moisture stress conditions. Jat *et al.* (2018) also have reported that the optimal irrigation (0.7-0.8 IW/CPE) applied to mustard resulted the higher oil content and oil yields than deficit irrigations (0.6 IW/CPE). In our study, the maximum decrease in oil yield due to moisture stress was recorded at the control (21.9 %) and least decrease in oil yield was recorded with the application of SAP either alone (14.5 %) or in combination with PBRs (4.3-5.9 %). This indicated that combined application of SAP and PBRs substantially reduced the oil yield loss due to moisture stress. Among different moisture stress mitigation options, the maximum oil yield was recorded with SAP+SA (1.10 t/ha), which was found on par with SAP+TU and SAP+PN but significantly higher by 8.8 and 30.3 % over the SAP and control treatments, respectively (Fig. 2). Comparatively higher oil content and seed yields led to significant increase in the oil yield of the mustard under SAP and PBR applied treatments.

Langadi *et al.* (2021) reported that application of SAP (2.5-5.0 kg/ha) significantly improved the oil yield (15.5-30.2 %) over the control and 1.5 kg SAP/ha. Choudhary *et al.* (2023) reported that application of SAP+SA, being on par with SAP+TU and SAP+PN improved mustard seed yield 8.7 and 24.6 % over the SAP and control treatments, respectively.

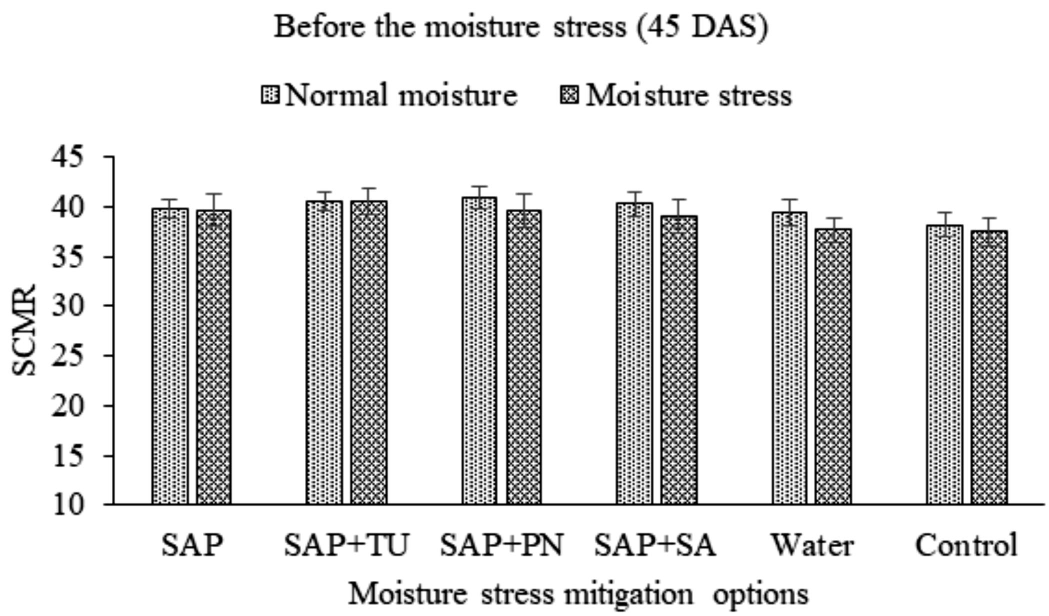

Fig. : Effect of soil moisture regimes and moisture stress mitigation options on SPAD-chlorophyll meter reading (SCMR) of Indian mustard

Economics

The cost of cultivation was increased with increase in inputs, consequently it was recorded higher under normal moisture regime (8.2 %) and under SAP+PBR applied treatments (7.6-19.3 %) over the moisture stress regime and without SAP+PBR applied treatments, respectively (Table 2). However, normal moisture regime resulted higher values of gross returns, net returns, B:C ratio as well as economic efficiency to the

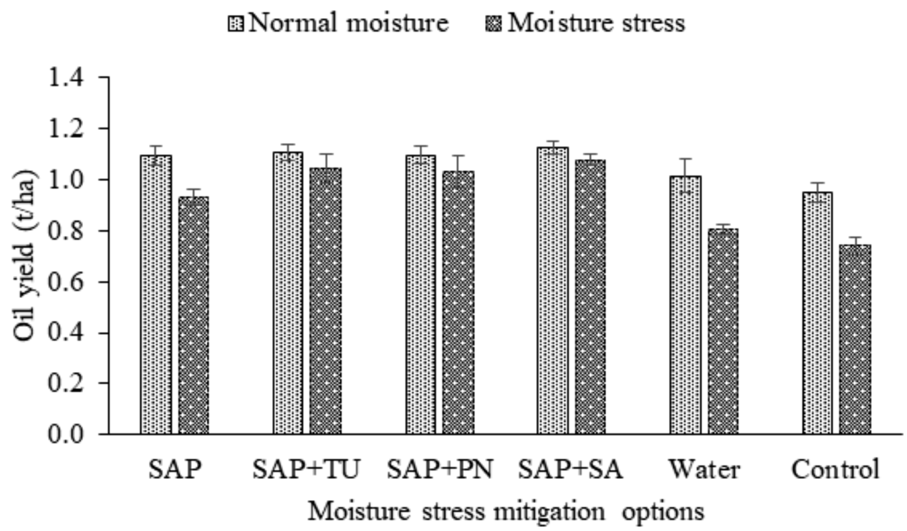

Fig. 2: Effect of soil moisture regimes and moisture stress mitigation options on oil yield of Indian mustard

tune of 12.3, 15.0, 6.6 and 15.1 %, respectively over the moisture stress regimes. Among different moisture stress mitigation options, the maximum values of gross returns (117.45 × 10^3 Rs./ha), net returns (75.15 × 10^3 Rs./ha) and economic efficiency (529 Rs./ha/day) were obtained with SAP+SA , which were found on par with SAP+TU/PN but significantly higher by 8.4 and 24.2 %, 12.2 and 34.0 % and 12.1 and 33.9 %, respectively over the SAP and control treatments. SAP+SA also resulted the maximum B:C ratio under both the moisture regimes, but it did not improve significantly under normal moisture regime. On the other hand, under moisture stress regime it significantly improved (18.1-43.0 %) with SAP+SA (1.83) over the rest of the treatments. The significant increase in net profit, B:C ratio and economic efficiency particularly under the moisture stress regime was due to increase in yields of the mustard which was mainly driven by mitigation of moisture stress in plants due to application of PBRs and through conserving and supply of moisture during the stress period by the SAP. Langadi *et al.* (2021) reported the higher values of gross returns, net returns, B:C ratio as well as economic efficiency to the tune of 19.3, 29.4, 25.3 and 29.4 %, respectively under the normal moisture over the moisture stress regimes. They further reported that the maximum profitability could be realized with application of 5.0 kg SAP/ha, which was being on par with 2.5 kg SAP/ha but significantly higher by 21.1-30.0 % over the control. Rathore *et al.* (2019) also reported that the highest net returns could be obtained with scheduling of irrigation at 0.8 IW/CPE + hydrogel (SAP). Further, the higher water storage capacity, irrigation water productivity and yields with SAP improves profitability (Montesano *et al.,* 2015; Kalhapure *et al.,* 2016).

Table 2: Effect of soil moisture regimes and moisture stress mitigation options on economics of Indian mustard

Soil moisture regimes	Moisture stress mitigation options						Mean
	SAP	SA P+TU	SAP+PN	SAP+SA	Water	Control	
Cost of cultivation (×10^3Rs./ha)							
Normal moisture	43.06	47.57	47.12	43.96	40.78	40.14	43.77
Moisture stress	39.73	44.25	43.80	40.64	37.46	36.81	40.45
Mean	41.39	45.91	45.46	42.30	39.12	38.47	0.00
Gross returns (×10^3Rs./ha)							
Normal moisture	116.74	118.00	117.67	120.07	107.64	105.03	114.19
Moisture stress	100.05	112.63	110.19	114.83	88.20	84.10	101.67
Mean	108.39	115.31	113.93	117.45	97.92	94.56	0.00

	A. Soil moisture regimes	B. Moisture stress mitigation options	A × B
SEm ±	1.54	2.66	3.77
LSD ($p \leq 0.05$)	4.51	7.81	NS

Net returns (×10³ Rs./ha)							
Normal moisture	73.68	70.43	70.55	76.10	66.86	64.89	70.42
Moisture stress	60.32	68.37	66.40	74.19	50.74	47.29	61.22
Mean	67.00	69.40	68.47	75.15	58.80	56.09	0.00
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm ±		1.54			2.66		3.77
LSD ($p \leq 0.05$)		4.51			7.81		NS
B:C ratio							
Normal moisture	1.71	1.48	1.50	1.73	1.64	1.62	1.61
Moisture stress	1.52	1.55	1.52	1.83	1.35	1.28	1.51
Mean	1.61	1.51	1.51	1.78	1.50	1.45	
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm ±		0.03			0.05		0.07
LSD ($p \leq 0.05$)		0.09			0.16		0.22
Economic efficiency (Rs./ha/day)							
Normal moisture	519	496	497	536	471	457	496
Moisture stress	425	482	468	522	357	333	431
Mean	472	489	482	529	414	395	
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm ±		10.8			18.8		26.5
LSD ($p \leq 0.05$)		31.8			55.0		NS

Correlation matrix

The correlation matrix between the yield and yield attributes of mustard subjected to different soil moisture regimes and moisture stress mitigation options (Table 3) showed that seed yield was strongly associated with the biological yield (r = 0.98), SCMR (r = 0.98), number of siliquae (r = 0.98), seed weight (r = 0.94), siliqua length (r = 0.93) and primary branches per plant (r = 0.93). There was a relatively weak relation between seed yield and number of secondary branches (r = 0.84), seeds per siliqua (r = 0.91) and 1000-seed weight (r = 0.92). Though, all the characters were positively related to each other. Correlation coefficient analysis showed that among those components number of siliquae, seed weight and siliqua length were the dominant contributors to seed yield.

Conclusion

The study revealed that soil moisture stress occurred during the reproductive stages of Indian mustard led to significant reduction in its growth, yield attributes, oil yield (11.8 %) and profitability (13.1 %). However, application of moisture stress mitigation options like superabsorbent polymer (SAP, pusa hydrogel) and plant bio-regulators (PBR's) like salicylic acid (SA), thiourea (TU) and potassium nitrate (PN) was found beneficial in mitigation of moisture stress and enhancing the profitability under limited water availability conditions. The maximum oil production and profitability was realized with combined application of SAP+SA followed by SAP+TU and SAP+PN. Thus, combined application of SAP and PBRs (especially SA) can be recommended to mitigate deficit moisture stress, saving of irrigation water and enhance the oil yield and profitability of Indian mustard in drought prone/ rainfed areas.

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Table 3: Correlation coefficient (r) among seed yield and yield attributes of Indian mustard under different soil moisture regimes and moisture stress mitigation options

Characters	Seed yield	SCMR	Primary branches	Secondary branches	Main shoot length	Siliquae no.	Siliqua length	Seeds/ siliqua	Seed weight/ plant	Test weight	Biological yield
Seed yield	-										
SCMR	0.98	-									
Primary branches	0.93	0.94	-								
Secondary branches	0.84	0.84	0.80	-							
Main shoot length	0.90	0.90	0.81	0.97	-						
Siliquae no.	0.98	0.98	0.95	0.87	0.91	-					
Siliqua length	0.93	0.93	0.97	0.87	0.86	0.97	-				
Seeds/ siliqua	0.91	0.90	0.93	0.91	0.86	0.93	0.96	-			
Seed weight/ plant	0.94	0.93	0.80	0.92	0.98	0.93	0.86	0.86	-		
Test weight	0.92	0.93	0.87	0.97	0.98	0.94	0.91	0.93	0.96	-	
Biological yield	0.98	0.97	0.96	0.89	0.92	0.98	0.96	0.95	0.92	0.94	-

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