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RESPONSE OF SESAME (*Sesamum indicum* L.) TO MOISTURE CONSERVATION PRACTICES AND FOLIAR ZINC AND BORON NUTRITION UNDER SEMI-ARID CONDITIONS

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ABSTRACT

Moisture deficiency is one of the major constraints limiting sesame productivity in semi-arid regions, as it adversely affects crop growth, physiological processes and yield development. Adoption of suitable moisture conservation measures along with balanced micronutrient nutrition can enhance physiological efficiency and crop productivity under rainfed conditions. Keeping this in view, a field experiment was conducted during the *Kharif* seasons of 2023 and 2024 at Agronomy Farm, S.K.N. College of Agriculture, Jobner, Rajasthan. The study was conducted in a split-plot design comprising seven moisture conservation practices, namely control, dust mulch, hydrogel @ 5.0 kg/ha, crop residue @ 2.5 t/ha, crop residue @ 5.0 t/ha, hydrogel @ 5.0 kg/ha + crop residue @ 2.5 t/ha and hydrogel @ 5.0 kg/ha + crop residue @ 5.0 t/ha in the main plots and four foliar nutrition treatments, *viz*., control, $ZnSO_4$ @ 0.5%, boric acid @ 0.2% and $ZnSO_4$ @ 0.5% + boric acid @ 0.2% in the sub-plots. The pooled results of two years indicated that both moisture conservation practices and foliar nutrition significantly affected the physiological behaviour of sesame. The application of crop residue @ 5.0 t/ha produced the higher plant height (122.43 cm), chlorophyll content (3.72 mg/g), leaf area index (3.226) and capsules per plant (28.30), which ultimately resulted in the higher seed yield (880 kg/ha) while found at par with hydrogel @ 5.0 kg/ha + crop residue @ 2.5 t/ha and hydrogel @ 5.0 kg/ha + crop residue @ 5.0 t/ha. Among the foliar nutrition treatments, the combined spray of $ZnSO_4$ @ 0.5% and boric acid @ 0.2% significantly improved plant height, chlorophyll content, leaf area index and capsules per plant compared with the control and individual micronutrient applications. The same treatment also recorded the maximum seed yield (872 kg/ha). The improvement in physiological performance under integrated moisture conservation and micronutrient management was mainly associated with better soil moisture retention, enhanced photosynthetic activity, efficient nutrient utilization and improved translocation of assimilates within the plant.

***Keywords*:** Sesame, hydrogel, crop residue, zinc sulphate, boric acid, seed yield.

Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest oilseed crops cultivated worldwide and is valued for its high-quality edible oil, protein, vitamins and antioxidant compounds such as sesamin, sesamolin and sesamol (Brar and Ahuja, 1979). Owing to its high oil content (46–52%) and nutritional richness, sesame is popularly known as the "queen of oilseeds" and plays an important role in the edible oil economy of many tropical and subtropical countries (Adeola *et al*., 2010). In India, sesame is cultivated under diverse agro-climatic conditions; however, its productivity remains relatively low due to moisture stress and nutrient deficiencies, particularly in arid and semi-arid regions.

Soil moisture scarcity is a major constraint limiting sesame productivity. The increasing pressure on freshwater resources necessitates the adoption of efficient moisture conservation practices to improve crop performance under rainfed conditions (Kreye *et al*., 2009). Mulching has been recognized as an effective strategy for reducing soil evaporation, improving water use efficiency, moderating soil temperature and enhancing crop productivity (Yaghi *et al*., 2013; Rummana *et al*., 2018). Likewise, hydrogels have emerged as promising soil conditioners capable of absorbing and gradually releasing large quantities of water, thereby improving soil moisture availability and nutrient use efficiency under drought-prone environments (Agaba *et al*., 2010; El-Asmar *et al*., 2017).

Micronutrient deficiencies, particularly zinc (Zn) and boron (B), are widespread in Indian soils and significantly affect crop growth, yield and quality (Shukla *et al*., 2021). Zinc plays a vital role in enzyme activation, photosynthesis, protein synthesis and hormonal regulation, whereas boron is essential for cell division, pollen germination, seed development and oil synthesis (Alloway, 2008; Soleimani, 2006). Foliar application of these micronutrients has been reported to improve nutrient availability, chlorophyll content, reproductive growth and yield attributes in oilseed crops (Shireen *et al*., 2018; Fahad *et al*., 2018).

Therefore, the integration of suitable moisture conservation practices with foliar nutrition may offer a sustainable approach to enhance growth, productivity and quality of sesame under moisture-limited environments. The present investigation was undertaken to evaluate the effect of different moisture conservation practices and foliar application of micronutrients on growth, yield, quality and nutrient uptake of sesame.

Materials and Methods

A field experiment was conducted during the *Kharif* seasons of 2023 and 2024 at Agronomy Farm, S.K.N. College of Agriculture, Jobner, Rajasthan, India (26°05′ N latitude, 75°28′ E longitude and 427 m above mean sea level). The experimental site falls under the Semi-Arid Eastern Plain Zone (Agro-climatic Zone IIIA) of Rajasthan. The soil of the experimental field was loamy sand in texture, alkaline in reaction (pH 8.05–8.08), low in organic carbon and available nitrogen, medium in available phosphorus and potassium, and deficient in available zinc and boron. During the crop growth period, the area received 403.4 mm and 735.3 mm rainfall during 2023 and 2024, respectively.

The experiment was laid out in a split-plot design with three replications. Seven moisture conservation practices *viz*., control, dust mulch, hydrogel @ 5.0 kg/ha, crop residue @ 2.5 t/ha, crop residue @ 5.0 t/ha, hydrogel @ 5.0 kg/ha + crop residue @ 2.5 t/ha and hydrogel @ 5.0 kg/ha + crop residue @ 5.0 t/ha, were assigned to the main plots. Four foliar nutrition treatments *viz*., control, 0.5% $ZnSO_4$, 0.2% boric acid and 0.5% $ZnSO_4$ + 0.2% boric acid, were allotted to the sub-plots. Sesame variety RT-351 was sown at a seed rate of 4 kg/ha with a spacing of 30 cm × 10 cm. Recommended doses of fertilizers (20 kg N and 25 kg P_2O_5/ha) were applied as per standard recommendations. Foliar sprays of zinc sulphate and boric acid were applied at 30 and 45 days after sowing (DAS).

Plant height was measured from the base of the plant to the tip of the main shoot on five randomly tagged plants in each plot and expressed in centimetres. Chlorophyll content was estimated from fully expanded leaves using the 80% acetone extraction method described by Arnon (1949) and expressed as mg/g fresh weight. Leaf area index (LAI) was calculated as the ratio of total leaf area to the corresponding ground area following the method suggested by Watson (1958). The number of capsules per plant was recorded from five tagged plants at harvest and averaged. Seed yield was obtained from the net plot area after threshing, cleaning and drying of produce and expressed in kg/ha.

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a split-plot design as described by Gomez and Gomez (1984). The significance of treatment effects was tested at the 5 per cent level of probability and treatment means were compared using the critical difference (CD) test.

Results and Discussion

Growth Parameters

Plant Height

Plant height at harvest was markedly influenced by different moisture conservation practices as well as foliar nutrition treatments. Among the moisture conservation options, application of crop residue @ 5.0 t/ha resulted in significantly taller plants compared to control, dust mulch, hydrogel @ 5.0 kg/ha and crop residue @ 2.5 t/ha. However, its effect was found to be statistically comparable with crop residue @ 2.5 t/ha + hydrogel @ 5.0 kg/ha and crop residue @ 5.0 t/ha + hydrogel @ 5.0 kg/ha. The favourable influence of residue mulch and hydrogel treatments on plant height could be attributed to improved soil moisture retention and better nutrient availability, which promoted cell division, cell elongation and overall vegetative growth. Comparable results have also been reported by Ashraf *et al*. (2020), Bana *et al*. (2023) and Bharati *et al*. (2024).

With respect to foliar nutrition, the combined application of 0.5% $ZnSO_4$ + 0.2% boric acid produced significantly greater plant height than the individual applications of zinc sulphate, boric acid and the untreated control. The beneficial effect of combined micronutrient application may be associated with the involvement of zinc and boron in auxin synthesis, enzymatic activities and cellular growth processes, which ultimately enhanced vegetative development (Cakmak, 2000; Silva *et al*., 2011).

Chlorophyll Content

Chlorophyll content measured at 50 DAS was significantly affected by both moisture conservation practices and foliar nutrition treatments. Among the moisture conservation treatments, crop residue @ 5.0 t/ha recorded significantly higher chlorophyll content than control, dust mulch, hydrogel @ 5.0 kg/ha and crop residue @ 2.5 t/ha. Nevertheless, it remained statistically similar to the treatments involving hydrogel in combination with crop residue. Pooled analysis indicated that crop residue @ 5.0 t/ha enhanced chlorophyll content by 26.96 per cent over the control treatment. The increase in chlorophyll concentration may be due to improved soil moisture status and nutrient uptake under mulched conditions, which helped maintain chlorophyll stability and delayed leaf senescence, thereby supporting greater photosynthetic activity. Similar findings have been documented by Bharati *et al*. (2024).

Among the foliar nutrition treatments, application of 0.5% $ZnSO_4$ + 0.2% boric acid registered the highest chlorophyll content and showed an improvement of 11.32 per cent over the control. Zinc is known to play a crucial role in chlorophyll formation and preservation of chloroplast structure, whereas boron facilitates metabolic processes and nutrient movement within the plant. The combined action of these micronutrients likely contributed to enhanced chlorophyll accumulation and improved photosynthetic efficiency (Cakmak, 2000).

Leaf Area Index

Leaf area index (LAI) at 60 DAS responded significantly to moisture conservation and foliar nutrition treatments. Among the moisture conservation practices, crop residue @ 5.0 t/ha produced significantly higher LAI than control, dust mulch, hydrogel @ 5.0 kg/ha and crop residue @ 2.5 t/ha. However, its performance was statistically comparable with the integrated treatments involving crop residue and hydrogel. The pooled data revealed that crop residue @ 5.0 t/ha increased LAI by 30.19 per cent over the control. The improvement in LAI can be attributed to favourable soil moisture conditions created by residue mulching, which encouraged leaf expansion, canopy growth and efficient interception of sunlight.

Similarly, foliar application of 0.5% $ZnSO_4$ + 0.2% boric acid recorded significantly higher LAI than the individual micronutrient treatments and the control. Enhanced chlorophyll synthesis, increased photosynthetic activity and improved cell division resulting from adequate zinc and boron supply may have contributed to greater leaf area development and canopy expansion.

Yield attribute and yield

Number of Capsules/Plant

The number of capsules per plant was significantly influenced by the moisture conservation practices and foliar nutrition treatments. Among the moisture conservation options, crop residue @ 5.0 t/ha produced significantly more capsules per plant than control, dust mulch, hydrogel @ 5.0 kg/ha and crop residue @ 2.5 t/ha. However, it remained statistically at par with the treatments comprising crop residue and hydrogel combinations. On a pooled basis, this treatment increased the number of capsules per plant by 29.58 per cent compared with the control. The increase in capsule production may be due to improved soil moisture availability during the reproductive phase, which reduced flower drop and supported better capsule development.

Foliar application of 0.5% $ZnSO_4$ + 0.2% boric acid also significantly increased the number of capsules per plant and recorded a 13.95 per cent improvement over the control. The positive response may be attributed to the role of zinc and boron in reproductive processes, including pollen viability, fertilization and efficient translocation of photosynthates, which ultimately enhanced capsule formation and retention.

Seed Yield

Seed yield was significantly affected by both moisture conservation practices and foliar nutrition treatments. Among the moisture conservation treatments, crop residue @ 5.0 t/ha recorded significantly higher seed yield than control, dust mulch, hydrogel @ 5.0 kg/ha and crop residue @ 2.5 t/ha. Its performance was statistically comparable with the treatments involving crop residue in combination with hydrogel. Based on pooled data, crop residue @ 5.0 t/ha increased seed yield by 32.33 per cent over the control. The higher productivity obtained under this treatment may be attributed to improved soil moisture conservation, enhanced chlorophyll content, greater leaf area development and increased capsule formation, all of which contributed to better production and translocation of assimilates towards the developing seeds.

Among the foliar nutrition treatments, the combined spray of 0.5% $ZnSO_4$ + 0.2% boric acid produced the highest seed yield with a pooled mean of 872 kg/ha and remained significantly superior to the individual applications of zinc sulphate, boric acid and the control. The combined micronutrient treatment improved seed yield by 14.89 per cent over the control. This improvement may be attributed to the complementary roles of zinc and boron in enhancing photosynthesis, nutrient utilization, reproductive efficiency and seed development, which collectively resulted in greater crop productivity.

Discussion

The findings of the present investigation demonstrated that moisture conservation practices and foliar nutrition exerted a significant influence on the growth, productivity, nutrient uptake, quality and economics of sesame under semi-arid conditions. Among the moisture conservation practices, application of crop residue @ 5.0 t/ha, either alone or in combination with hydrogel, markedly improved plant height, chlorophyll content, leaf area index, capsules per plant and seed yield over control and other treatments. These improvements may be attributed to enhanced soil moisture availability, reduced evaporation losses and improved nutrient utilization, which collectively promoted vegetative growth, photosynthetic activity and reproductive development. The favourable soil moisture regime created by residue mulch and hydrogel maintained adequate water availability throughout the crop growth period, resulting in improved plant-water relations, greater biomass accumulation and efficient translocation of assimilates towards developing reproductive structures (Al-Harbi *et al*., 1999; Verma, 2002; Bharati *et al*., 2024).

Foliar nutrition treatments also produced marked improvements in growth and yield parameters. Foliar application of 0.5% $ZnSO_4$ + 0.2% boric acid significantly increased plant height, chlorophyll content, leaf area index, capsules per plant and seed yield compared with individual micronutrient applications and control. The beneficial effect may be attributed to the complementary physiological functions of zinc and boron. Zinc plays an important role in chlorophyll synthesis, enzyme activation, protein formation and auxin metabolism, whereas boron is essential for cell division, assimilate translocation, pollen viability and seed development. The combined application of these micronutrients improved photosynthetic efficiency and metabolic activity, resulting in greater biomass production and enhanced reproductive growth (Cakmak, 2000; Alloway, 2008; Silva *et al*., 2011).

Conclusion

Among the moisture conservation treatments, crop residue @ 5.0 t/ha proved most effective and recorded significantly higher plant height, chlorophyll content, leaf area index, capsules per plant and seed yield. Although integrated application of hydrogel and crop residue improved several growth and physiological parameters, crop residue @ 5.0 t/ha alone emerged as the most economically viable treatment. Among foliar nutrition treatments, foliar spray of 0.5% $ZnSO_4$ + 0.2% boric acid significantly enhanced growth attributes, yield-contributing characters and seed yield compared with individual micronutrient applications and control.

Therefore, based on overall growth and productivity, application of crop residue @ 5.0 t/ha along with foliar spray of 0.5% $ZnSO_4$ + 0.2% boric acid at 30 and 45 DAS may be recommended as an effective and economically sustainable production strategy for sesame cultivation under the semi-arid conditions of Rajasthan and other similar agro-ecological regions.

Table 1 : Effect of moisture conservation practices and foliar nutrition on plant height, chlorophyll content and leaf area index of sesame.

Treatment	Plant height (cm)			Chlorophyll content (mg/g)			Leaf area index at 60 DAS		
	At harvest			60 DAS			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Moisture conservation practices									
Control	88.96	93.27	91.12	2.85	3.01	2.93	2.469	2.488	2.478
Dust mulch	98.90	102.93	100.91	3.13	3.24	3.19	2.708	2.727	2.717
Hydrogel @ 5.0 kg/ha	108.77	112.77	110.77	3.40	3.46	3.43	2.927	2.961	2.944
Crop residue @ 2.5 t/ha	109.99	114.56	112.28	3.45	3.52	3.48	2.979	2.999	2.989
Crop residue @ 5.0 t/ha	120.40	124.46	122.43	3.73	3.71	3.72	3.215	3.236	3.226
Hydrogel @ 5.0 kg/ha + Crop residue @ 2.5 t/ha	121.75	125.84	123.79	3.75	3.74	3.74	3.269	3.267	3.268
Hydrogel @ 5.0 kg/ha + Crop residue @ 5.0 t/ha	123.52	128.04	125.78	3.79	3.81	3.80	3.304	3.312	3.308
SEm±	3.19	3.08	2.22	0.046	0.047	0.033	0.069	0.075	0.051
CD (P=0.05)	9.82	9.49	6.47	0.142	0.146	0.096	0.212	0.230	0.148
CV(%)	10.00	9.31		4.64	4.69		7.98	8.63	
Foliar nutrition									
Control	100.83	104.98	102.91	3.24	3.28	3.26	2.833	2.850	2.842
0.5% Zinc Sulphate	109.06	113.44	111.25	3.45	3.52	3.48	2.968	2.987	2.977
0.2% Boric acid	111.70	115.87	113.78	3.47	3.53	3.50	3.000	3.018	3.009
0.5% Zinc Sulphate + 0.2% Boric acid	119.72	123.91	121.81	3.60	3.66	3.63	3.125	3.139	3.132
SEm±	2.37	2.31	1.66	0.034	0.034	0.024	0.044	0.042	0.030
CD (P=0.05)	6.76	6.60	4.66	0.096	0.096	0.067	0.124	0.119	0.085
CV(%)	9.84	9.25		4.47	4.41		6.70	6.39	

Table 2 : Effect of moisture conservation practices and foliar nutrition on yield attribute and yield of sesame

Treatment	Capsules/plant			Seeds yield		
	2023	2024	Pooled	2023	2024	Pooled
Moisture conservation practices						
Control	21.60	22.07	21.84	654	675	665
Dust mulch	23.63	24.18	23.91	719	743	731
Hydrogel @ 5.0 kg/ha	25.74	26.21	25.97	786	815	800
Crop residue @ 2.5 t/ha	26.20	26.44	26.32	800	825	813
Crop residue @ 5.0 t/ha	28.23	28.37	28.30	865	895	880
Hydrogel @ 5.0 kg/ha + Crop residue @ 2.5 t/ha	28.66	28.96	28.81	890	918	904
Hydrogel @ 5.0 kg/ha + Crop residue @ 5.0 t/ha	29.06	29.76	29.41	906	937	922
SEm±	0.62	0.61	0.44	20	22	15
CD (P=0.05)	1.92	1.89	1.28	63	68	44
CV(%)	8.26	7.99		8.83	9.20	
Foliar nutrition						
Control	24.41	24.87	24.64	747	772	759
0.5% Zinc Sulphate	25.91	26.31	26.11	795	824	809
0.2% Boric acid	26.46	26.81	26.64	812	837	825
0.5% Zinc Sulphate + 0.2% Boric acid	27.86	28.29	28.07	857	887	872
SEm±	0.46	0.42	0.31	14	13	10
CD (P=0.05)	1.31	1.21	0.88	41	37	27
CV(%)	8.06	7.31		8.19	7.08	

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