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Enhancing stress mitigation in okra cultivation through hydrogel and vermicompost applications in water-limited environments

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Abstract

Abiotic stresses like water scarcity and poor soil conditions limit the productivity of rainfed agriculture in Jharkhand, India. Predominantly, rice, maize, and pulses are mono-cropped over large areas, while vegetables such as okra are less cultivated due to limited water availability and low soil water-holding capacity, particularly during post-rainy seasons. This study evaluates the potential of two hydrogels, Pusa Hydrogel and SPG-1818 Hydrogel, in improving soil moisture retention and mitigating water stress to support vegetable cultivation. Both hydrogels are superabsorbent polymers capable of significantly enhancing the soil's water-holding capacity. Field experiments were conducted using hydrogels in combination with vermicompost at various levels. The results demonstrated that the application of SPG-1818 Hydrogel also showed superior performance in reducing Stress Degree Days (SDD) and improving yield attributes such as the number of branches, leaves, pods, and overall biomass. Among treatments, SPG-1818 Hydrogel at 20 kg/ha combined with 2 kg/ha vermicompost (T13) emerged as the most effective, achieving a 73.1% increase in yield compared to the control. These findings underscore the potential of hydrogel-based soil amendments for enhancing water-use efficiency, alleviating drought stress, and improving crop resilience in water-limited regions. The study highlights hydrogels as a sustainable, cost-effective approach to support vegetable cultivation in arid and semi-arid regions.

Keywords: Hydrogels, soil moisture retention, stress degree days, vermicompost, water scarcity

Introduction

The most pressing issue for Indian agriculture is constituted by abiotic stresses, especially in the case of rainfed agriculture of Jharkhand due to irregular monsoons, undulating terrain, and low irrigation potential (10-12%). This has limited the farming system to a mono-cropping system primarily dominated by rice, maize, and pulses covering almost 38 lakh hectares of cultivable land. Vegetables are grown over about 2.9 lakh ha with only some irrigation support from wells and ponds. The state is very amenable for vegetables, particularly cauliflower and cabbage. However, cash crops like okra grow only in assured irrigation areas because the soils have low water-holding capacity of 20-22% at field capacity.

Okra (*Abelmoschus esculentus*) is a nutritious vegetable crop grown in hot and humid climates all around the world. In the 2023-2024 periods, Jharkhand cultivated okra over an area of approximately 10.217 thousand hectares, yielding a production of about 164.559 thousand tones. However, okra cultivation is influenced majorly by two constraints: water scarcity and poor soil conditions. Improvement of soil water retention due to the application of hydrogels offers an opportunity for further extension of vegetable cultivation leading towards higher income generation for the farmers and removal of water-related issues.

Hydrogels are natural or synthetic soil conditioners, which heavily improve the water-holding capacity of soil. These superabsorbent polymers can absorb 100 times their weight and release this water slowly, reducing drought stress and establishing and growing crops. Pusa Hydrogel and SPG-1818 Hydrogel, developed by IARI, possess outstanding water-absorbing capacities. SPG-1818 showed better performance. These hydrogels reduce evaporation, enhance soil physical properties and diminish the loss of fertilizers and herbicides, so it is capable of working at sites with scanty water supply also.

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Considering climatic and soil constraints of the region, a study was made on the prospect of hydro gel technologies for augmenting soil water management and productivity. The objectives of experiment was to assess hydrogel's effect on soil moisture retention and release and also to assess the impact of induced regimes of moisture by hydrogels on the performance of okra in acid-alfisol soils. This research will help develop a sustainable approach for vegetable cultivation under water-limited conditions. This will ensure increased production and income levels for farming communities.

Materials and Methods

A field experiment was conducted during the winter seasons of 2020-21 and 2021-22 at the Agrotechnology Park, Birsa Agricultural University Ranchi located at 23°17'N latitude, 83°17' E longitude and at an altitude of 625 meters above MSL. It comes under a semi-arid and subtropical climate. The experimental field was sandy loam in texture with 55.6% sand, 35% silt, and 9.4% clay. The surface soil of the field was acidic with the medium in organic carbon 0.85%, available N 465 kg/ha, available P₂O₅ 28.72 kg kg/ha, and available K₂O 238.5 kg kg/ha. Besides bulk densities of the soil were 1.49 and 1.59 g-cm⁻³ in 0-15 and 15-30 cm depth. The experiment was laid out in randomized block design with fourteen treatments and three replications. The treatments included two types of hydrogels, Pusa hydrogel and SPG-1818 hydrogel, each applied at rates of 5 kg, 10 kg, and 20 kg /ha. A control plot without hydrogel application was also included to serve as a baseline for comparison. To evaluate the combined effects of hydrogel and organic inputs, each hydrogel treatment was paired with vermicompost applied at a uniform rate of 2 kg /ha. Additionally, the control treatment was also combined with vermicompost to account for its individual effects. In total, the experiment involved fourteen treatment combinations: six treatments with Pusa hydrogel at different rates, six treatments with SPG-1818 hydrogel at corresponding rates, and two control treatments (with and without vermicompost). Thus the total treatment combinations were - T1-Pusa hydrogel at 5 kg / ha.; T2-Pusa hydrogel at 10 kg / ha.; T3-Pusa hydrogel at 20 kg / ha.; T4-PG-1818 hydrogel at 5 kg /ha.; T5-SPG-1818 hydrogel at 10 kg /ha.; T6- SPG-1818 hydrogel at 20 kg /ha; T7- Control (no hydrogel application); T8- Pusa hydrogel at 5 kg /ha + vermicompost at 2 kg /ha; T9- Pusa hydrogel at 10 kg /ha + vermicompost at 2 kg /ha; T10- Pusa hydrogel at 20 kg /ha + vermicompost at 2 kg /ha; T11- SPG-1818 hydrogel at 5 kg /ha + vermicompost at 2 kg /ha; T12- SPG-1818 hydrogel at 10 kg /ha + vermicompost at 2 kg /ha; T13- SPG-1818 hydrogel at 20 kg /ha + vermicompost at 2 kg /ha; T14- Control (no hydrogel) + vermicompost at 2 kg /ha. The fertilizers were applied in the proportions of 100:50:50 NPK kg ha⁻¹ in the form of urea, SSP, and MOP, respectively. The crop okra was sown on 13th February 2021 and harvested on 25th June, 2022 in both the seasons. The row to row and plant to plant spacing for okra was maintained at 25X40 cm respectively.

Results and Discussion

Stress Degree Days (SDD) during crop period of Okra

Overview: Hydrogels significantly affected the Stress Degree Days (SDD) during the crop period of okra. Both Pusa and SPG hydrogels reduced crop stress to a greater extent as the soil moisture status was better compared to the control. Among them, SPG hydrogel showed excellent performance in reducing stress conditions, as also shown by the study of Saini & Malve, (2023)^[6], in which it was shown that the effectiveness order was

20 g gel/pot > 10 g gel/pot > 5 g gel/pot. It also pointed out that SPG hydrogel had a better water retention capacity than the other hydrogels.

Pusa Hydrogel: Okra control treatment T7: hydrogel in the absence of vermicompost showed a positive SDD of 0.1 to 1.3, which may indicate higher stress as a result of soil moisture levels being below that which can be held. On the contrary, the different rates of applying Pusa hydrogel (T1: 5 kg gel/ha; T2: 10 kg gel/ha; T3: 20 kg gel/ha) generated a negative mean SDD across all treatments ranged from -1.7 to -0.3 in the same order of T3 > T2 > T1 (Fig. 23a). This would imply that the Pusa hydrogel maintained effective soil moisture, thereby minimizing the leaf/canopy temperature relative to the ambient air temperature, as confirmed by Dhiman *et al.* (2021)^[1], which stated that hydrogels enhance the retention of water in the soil and crop comfort under stress conditions.

When vermicompost was added, the same trend of the negative SDD values was observed (Figure 23b). The Pusa hydrogel efficacy was quite low with the addition of vermicompost. However, Saini & Malve. (2023)^[7] stated that synergy is present for the hydrogel with organic amendment, which might be an indication that it is the inherent characteristics of the Pusa hydrogel that don't allow much interference with organic amendments.

SPG Hydrogel: The SPG hydrogel treatments (T4: 5 kg gel/ha, T5: 10 kg gel/ha, T6: 20 kg gel/ha) had negative SDD values during the crop period without vermicompost, ranging between -2.8 and -1.1 in the sequence T6 > T5 > T4 (Figure 24a). The results were similar for the treatments of incorporation of vermicompost; the negative SDD values indicated higher stress alleviation than the control and Pusa hydrogel treatments (Figure 24b).

It is inferred that Saini & Malve, (2023)^[6] reported that the efficiency of SPG hydrogel was better when it was demonstrated through increased water absorbability with slower release, but addition of vermicompost enhanced the effect of SPG hydrogel by the soil structural and moisture movement by way of following Miller & Naeth., 2019.^[5]

Organic amendment significantly supports enhancing the efficiency of the hydrogel Comparisons: It could be inferred that SPG hydrogel was more efficient than Pusa hydrogel in depleting the SDDs both in the presence and absence of vermicompost, as depicted from Figures 23a, 23b, and 24a, 24b. A very high and significantly improved level of vermicompost application augmented the effectiveness of SPG hydrogel while almost having no impact on Pusa hydrogel. The superior performance of hydrogel SPG with vermicompost may be attributed to its enhanced moisture-holding capacity and the synergistic impacts of vermicompost thereby improving soil microbial activity and availability of nutrients. These results are in step with the conclusions of Saini & Malve. (2023)^[7] regarding the combined effect of interaction between hydrogels and organic amendments for management of stresses and crop growth after that.

Thus the findings of this study have highlighted the excellent potential of SPG hydrogel, especially with vermicompost, for the reduction of SDDs and mitigation of stress conditions during the crop period of okra. The present study is aimed toward the importance of the integration of advanced soil moisture management techniques along with organic amendments for optimized crop performance under moisture-stress conditions, as suggested by Miller & Naeth, (2019)^[5] and Dhiman *et al.* (2021)^[1].

Yield Attributes and Yield

Number of Branches: T7 (Control - No gel) produced as high as 1.8 branches per plant and that T14 was noted 5.6% enhanced through vermicompost. Maximum branches recorded in T13 with SPG-1818 hydrogel @ 20 kg ha⁻¹ + vermicompost (3.0), which were very well improved to be on par 66.7% than T7 and 57.9% better than T14. It had immense implications, perhaps because of some kind of synergy of SPG-1818 hydrogel combined with vermicompost, which enhanced both water holding capacities and nutrient availability in soils for promoting vegetative growth. Hydrogels have also been reported to enhance vegetative growth by Dhiman *et al.* (2021)^[1].

No. of leaves: All these treatments increased this value significantly, but much more remarkably when the T13 caused highest value at 19.7 leaves; 77.5 percent of T7 had 11.1 leaves, whereas 64.2 percent of that in T14, which has an approximate value at 12.0 leaves, is probably an indicator of better moisture and nutrients from the hydrogel-vermicompost combination from T13. These are in congruence with Kaur *et al.* (2023)^[3], whereby the hydrogels were demonstrated to be an effective tool in promoting vegetative growth under restricted moisture levels.

Pods per plant: Pods per plant was significantly differing between treatments; the lowest recorded pods per plant were in T7 at 1.0 pods per plant while the highest was in T13 at 2.8 pods per plant. This was an increase of 180% from T7 and 133.3% from T14 (1.2 pods per plant). SPG-1818 hydrogel with vermicompost appears to enhance reproductive growth in T13 by maintaining soil moisture at favorable levels to improve pod formation and nutrient uptake. This is in line with Gopinath *et al.* (2008)^[2], which noted that the similar positive reproductive traits changes were related to the hydrogel-based amendments in soils.

Total Pods per Plot: The total number of pods per plot for the treatment lines had high variation. For the control, T7, the total number was 337.2 pods. With this, there was a 7.1% increase for T14 that obtained a total number of 361.3 pods. T13 recorded the highest with a total of 564.2 pods, and it was by an increase

of 67.4% compared to T7 and 56.2% over T14. This increase in the number of pods under T13 could be due to enhanced water and nutrient supply, which enhances the overall productivity of the plants. Kumawat *et al.* (2024)^[4] have also presented similar trends where hydrogel and organic amendments greatly increase yield components.

Root Length and Weight: With hydrogel and vermicompost application, both root length and weight increased enormously. While for the control or T7 it was 21.4 cm, T14 showed 22.1 cm at +3.3%, yet it went all the way to 29.5 cm with T13 (37.9% higher as compared to the control, or +33.5% as above T14). Root weight also increased from 18.8 g of T7 to 19.5 g of T14 (+3.7%) and reached its peak of 36.1 g in T13 (+92.0% above T7, +85.1% compared to T14). It can thus be attributed to effective aeration and moisture retention by the hydrogel-vermicompost mixture, as concluded by Saini & Malve, (2023)^[6].

Shoot Weight: Shoot weight was significantly affected by the treatments, with T13 having the highest value at 116.9 g, 157.4% higher than T7 at 45.4 g, and 136.2% higher than T14 at 49.5 g. This biomass increase can be attributed to increased photosynthetic activity and nutrient translocation under optimal soil moisture and fertility conditions, as also reported by Kaur *et al.* (2023)^[3].

Yield (q ha): The treatments had a very significant effect on grain yield. Whereas control T7 was at 45.0 q ha², the yields were only marginally improved with T14 at 48.2 q ha² (+7.1%). A maximum increase of 77.9 q ha², corresponding to 73.1% above T7 and 61.6% above T14, was obtained with T13. Improvement in vegetative growth, reproductive properties, and biomass production can be collectively justified regarding the combined application with SPG-1818 hydrogel and vermicompost. Similar effects were reported by Gopinath *et al.* (2008)^[2] and Kumawat *et al.* (2024)^[4], indicating such improvements are in response to a positive role for crop productivity provided by soil amendment.

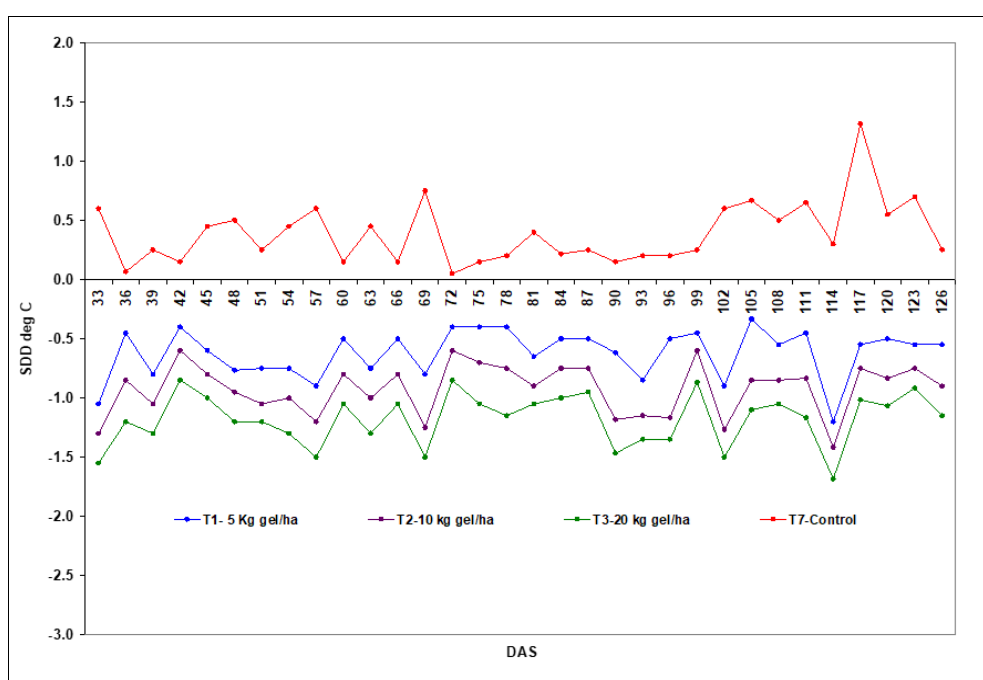


Fig 1a: Effect of different levels of Pusa Hydrogel, without vermicompost, on Stress Degree Days during crop period of Okra in Field experiment

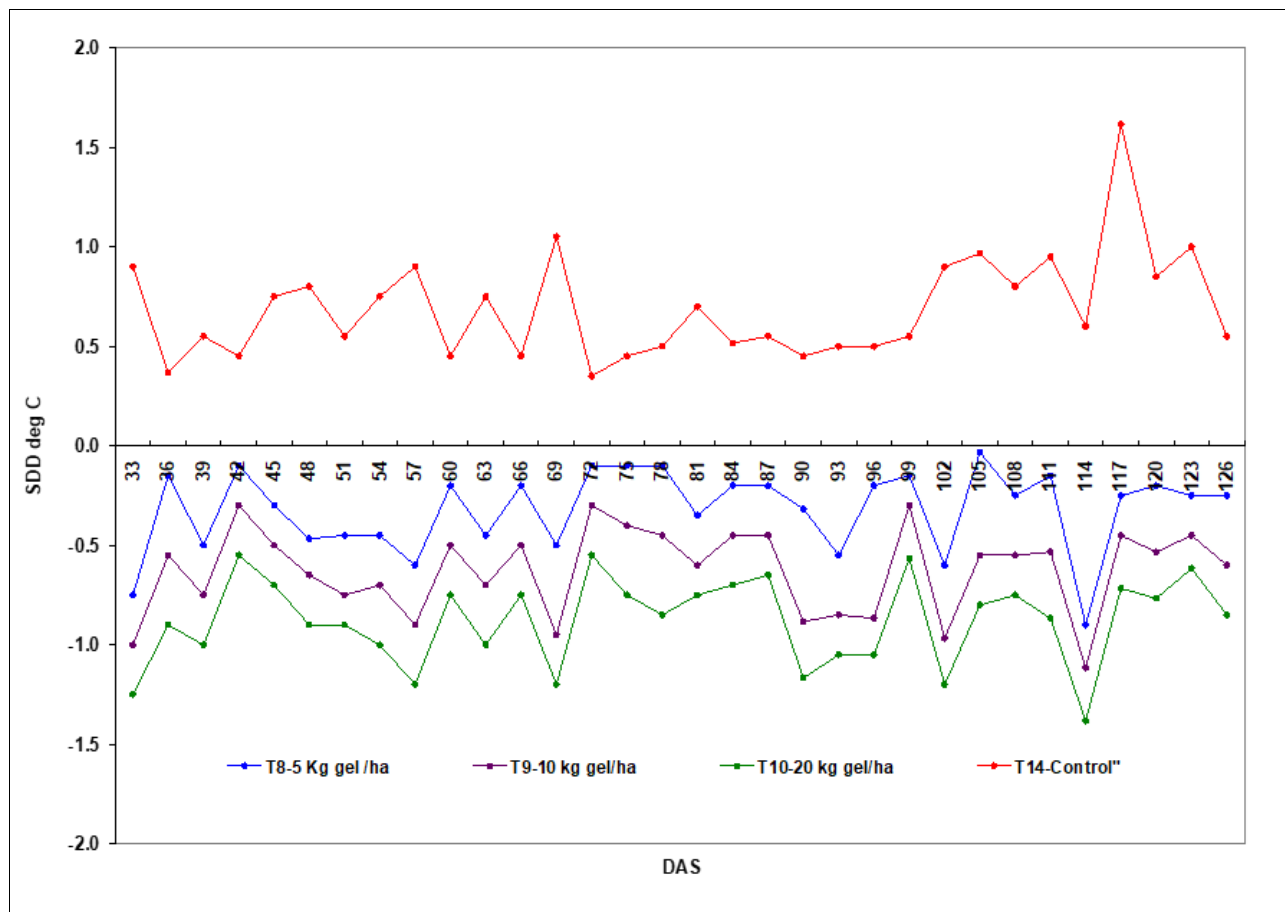


Fig. 1b: Effect of different levels of Pusa Hydrogel, with vermicompost, on Stress Degree Days during crop period of Okra in Field experiment

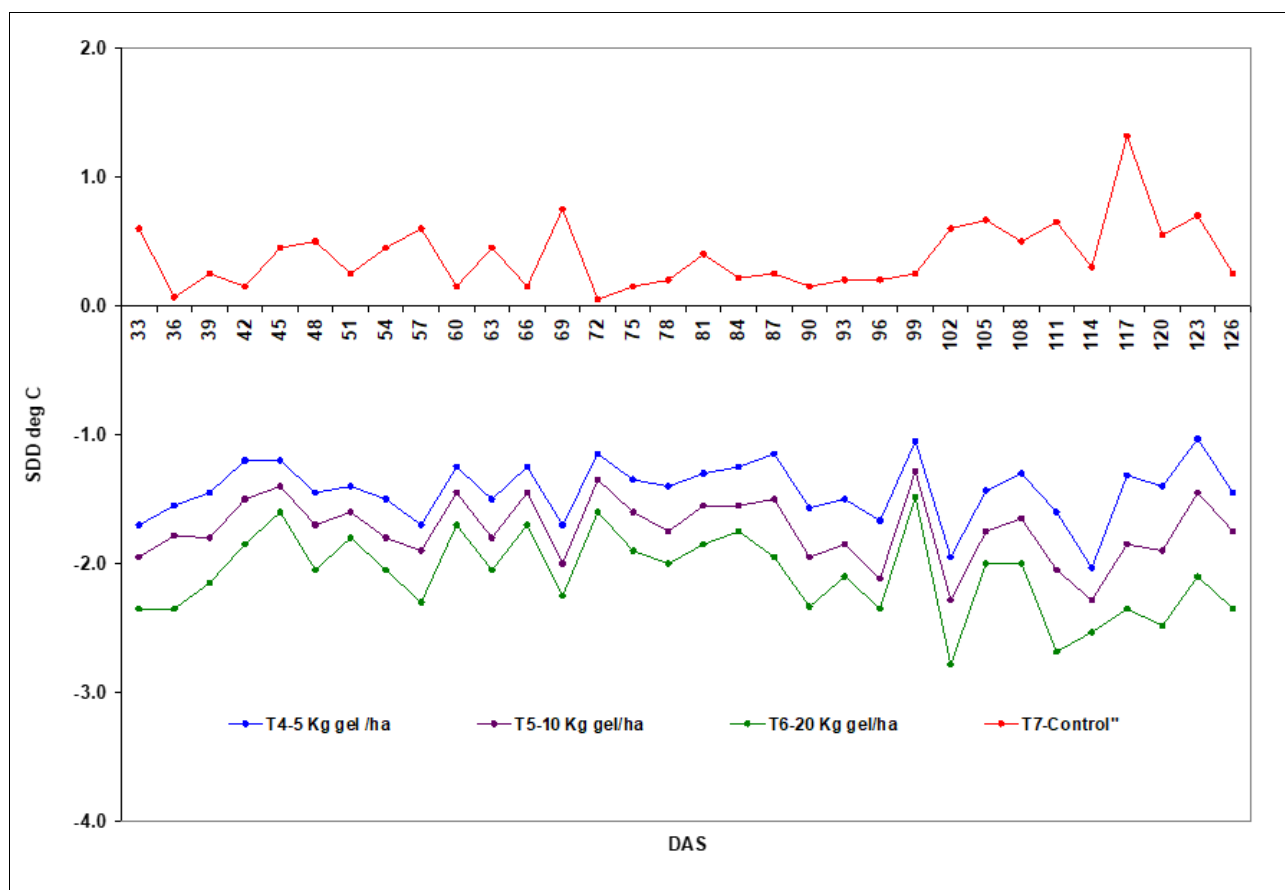


Fig. 1c: Effect of different levels of SPG Hydrogel, without vermicompost, on Stress Degree Days during crop period of Okra in Field experiment

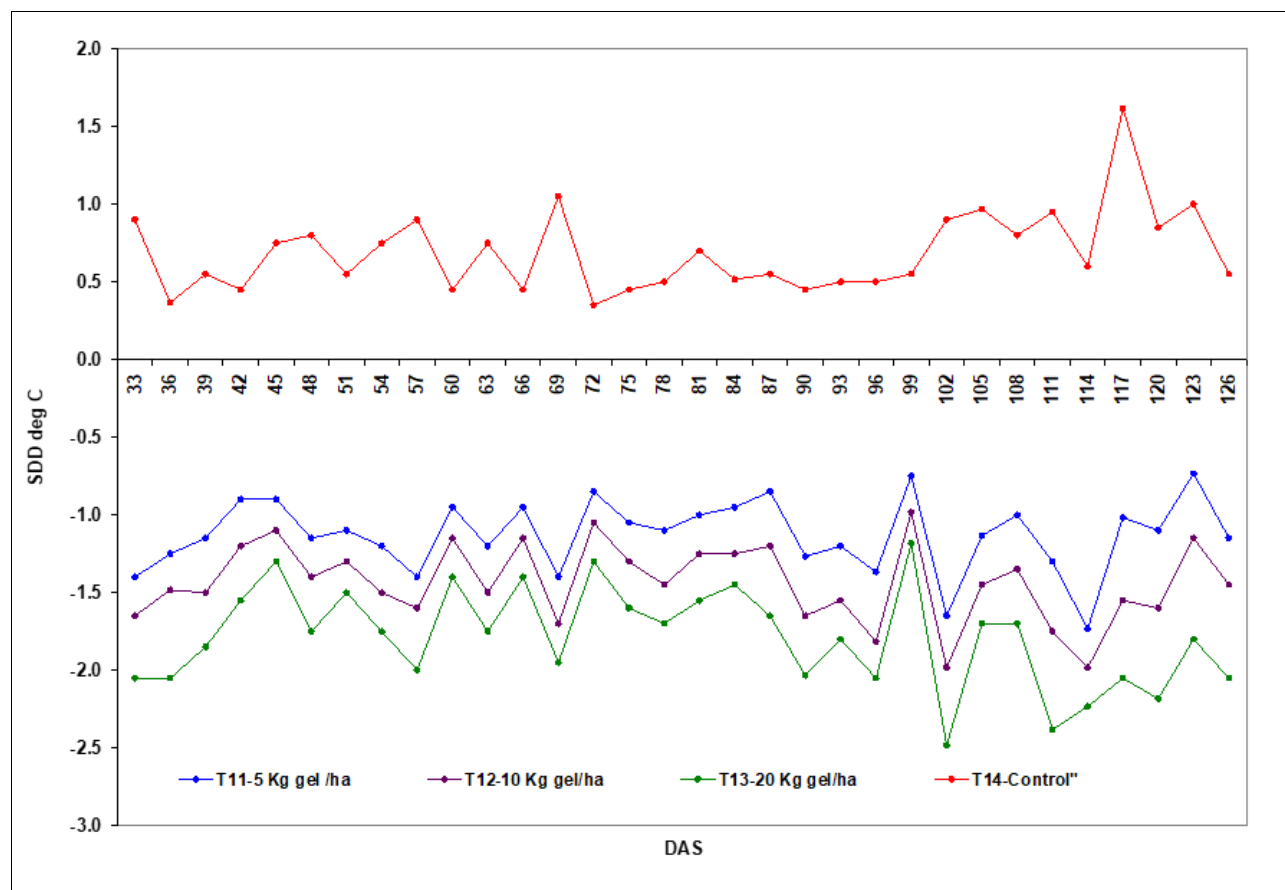


Fig. 1d: Effect of different levels of SPG Hydrogel, with vermicompost, on Stress Degree Days during crop period of Okra in Field experiment

Table: Effect of different levels of Pusa and SPG hydrogel with and without vermicompost on yield attributes and yield (pooled of two years)

Treatments	No. of branches	No. of leaves	No. of pods	Total Pods per plot	Root Length (cm)	Root Weight (g)	Shoot Weight (g)	Yield (q ha ⁻¹)
T1 Pusa hydrogel @ 5 kg ha ⁻¹	2.0	12.5	1.3	366.2	23.0	21.2	53.0	50.5
T2 Pusa hydrogel @ 10 kg ha ⁻¹	2.1	13.6	1.5	381.9	23.9	22.9	59.6	53.4
T3 Pusa hydrogel @ 20 kg ha ⁻¹	2.2	14.2	1.7	402.4	24.7	24.4	65.2	56.6
T4 SPG-1818 hydrogel @ 5 kg ha ⁻¹	2.2	15.0	1.9	438.8	25.7	26.3	73.5	59.1
T5 SPG-1818 hydrogel @ 10 kg ha ⁻¹	2.4	15.7	2.0	459.2	26.8	29.2	79.1	62.4
T6 SPG-1818 hydrogel @ 20 kg ha ⁻¹	2.6	16.7	2.3	510.8	28.4	32.1	96.4	72.2
T7 Control (No gel)	1.8	11.1	1.0	337.2	21.4	18.8	45.4	45.0
T8 T1 + Vermicompost (@ 2 kg ha ⁻¹)	2.1	12.8	1.5	383.5	23.2	23.0	56.7	49.1
T9 T2 + Vermicompost (@ 2 kg ha ⁻¹)	2.3	13.8	1.7	404.7	24.1	25.2	63.5	54.6
T10 T3 + Vermicompost (@ 2 kg ha ⁻¹)	2.4	14.7	2.0	424.5	25.0	27.2	68.5	57.7
T11 T4 + Vermicompost (@ 2 kg ha ⁻¹)	2.4	15.9	2.2	452.3	26.9	29.7	77.1	64.8
T12 T5 + Vermicompost (@ 2 kg ha ⁻¹)	2.7	17.3	2.4	483.0	27.9	32.8	92.5	68.3
T13 T6 + Vermicompost (@ 2 kg ha ⁻¹)	3.0	19.7	2.8	564.2	29.5	36.1	116.9	77.9
T14 T7 + Vermicompost (@ 2 kg ha ⁻¹)	1.9	12.0	1.2	361.3	22.1	19.5	49.5	48.2
S.Em±	0.07	0.33	0.07	8.61	0.3	0.69	2.6	1.35
CD at 5%	0.55	3.0	16.9	99.7	3.3	6.8	26.3	16.9
	0.20	0.95	0.20	24.88	0.87	1.99	7.51	3.90

Conclusion

Obviously, the integrated use of SPG-1818 hydrogel and vermicompost increased the yield attributes and grain yield of the crop subjected to such treatment in the experiment. Among the treatments, T13 (SPG-1818 hydrogel @ 20 kg ha⁻¹ + vermicompost @ 2 kg ha⁻¹) proved to be an efficient treatment with the maximum vegetative growth (no. of branches and leaves), reproductive attributes (no. of pods and total pods/plot), and biomass production (root and shoot weight), and that increased grain yield by 73.1% over control, T7.

These results have promise in the development of hydrogel-based organic amendments to improve soil moisture retention,

nutrient availability, and crop productivity under moisture-limiting conditions. For arid and semi-arid environments, this approach may emerge as a promising gap-filling strategy with sustainable implications in agriculture. Long-term assessments, cost-benefit analysis, and validation at the field level in various cropping systems and agro-climatic zones will further consolidate these results.

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